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Meteorological Analysis of 1964-65 ICAO Turbulence Data

Technical Memorandum WBTM TDL 14

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U.S. DEPARTMENT OF COMMERCE
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METEOROLOGICAL ANALYSIS OF 1964-65 ICAO TURBULENCE DATA

DeVer Colson

OFFICE OF SYSTEMS DEVELOPMENT
TECHNIQUES DEVELOPMENT LABORATORY

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ABSTRACT

Summaries are given of clear air turbulence (CAT) data over Alaska, Canada, Greenland, North Atlantic, Caribbean, Mexico, and Central America during four 5-day periods (December 1964, March, June, and September 1965) in the ICAO worldwide high-level turbulence collection program. Turbulence reports are summarized by intensity, altitude layer ($<$30,000, 30,000-33,999, $\geqslant$34,000 ft.), and location by 5-degree latitude-longitude square.

Meteorological analyses are presented showing probability of moderate or greater turbulence in relation to 300-mb circulation patterns, jet streams, isotachs, horizontal wind shear, and contour gradients. While no sharply defined criteria are established for routine prediction of occurrence of intensity of CAT, some interesting meteorological patterns associated with unusually turbulent conditions are shown. The study illustrates the importance of large values of wind speed, wind shear, and contour gradients and also rapidly increasing values of these parameters. The study particularly shows the importance of sharply curved flow patterns around troughs and ridges.

In general, the probability of both light or greater, and moderate or greater turbulence decreased with increasing altitude, but severe turbulence was more frequent in the top layer than in the two lower layers. Probability of turbulence was lower in the March period than in the December period. The probability decreased slightly in the June period but increased sharply in the September period. The probability of turbulence was somewhat, but not pronouncedly, higher over land than over ocean areas. Average duration of turbulence was less, and the average airspeed fluctuation in turbulent conditions was greater as the intensity of turbulence increased. However, the range of values within turbulence intensity classes was greater than the differences among intensity classes.

I. INTRODUCTION

The study of clear air turbulence (CAT) has long been hampered by a scarcity of complete and reliable observations of the phenomenon. In order to be reasonably useful for research, aircraft turbulence reports must include information on areas of smooth flight as well as reports of turbulence encounters. To provide a body of such data, the International Civil Aviation Organization (ICAO) in 1964 organized a series of four 5-day world-wide data collection periods: 9-14 December 1964, 10-15 March 1965, 9-14 June 1965, and 8-13 September 1965. During these periods, pilots were requested to fill out special data cards for all turbine flights at 20,000 feet mean sea level (MSL) and higher, including flights encountering no clear air turbulence.

The special data cards provided space for pilots to fill out the following items for all flights at 20,000 ft. mean sea level or higher.

a. Type of aircraft.
b. Departure and destination terminals and intermediate check points.
c. Cruising level, including major changes.
d. Departure and arrival date and time (Greenwich).

A box was provided which could be checked if no turbulence (or only very slight turbulence) was encountered. If turbulence was encountered, the pilots were asked to fill out a separate column for each turbulence encounter, providing information on:

a. Intensity (Light, moderate, severe, or extreme).
b. Position of aircraft (either by distance from a known station or by latitude and longitude) at onset of turbulence.
c. Time of onset of turbulence (Greenwich).
d. Duration of turbulence in minutes.
e. Whether turbulence was intermittent or continuous.
f. Flight level at onset of turbulence.
g. Indicated airspeed at onset of turbulence, in knots.
h. Airspeed fluctuations during turbulence, in knots.
i. True air temperature at onset of turbulence, in °C.
j. Wind direction and speed in knots at onset of turbulence.
k. Whether in clouds, in and out of clouds, or in the clear.
l. Whether in or adjacent to towering cumulus, thunderstorm, or cirrus.
m. Remarks on abrupt changes in temperature, whether flying at reduced airspeed when turbulence was encountered, etc.

Unfortunately, many data cards were not completely filled out.

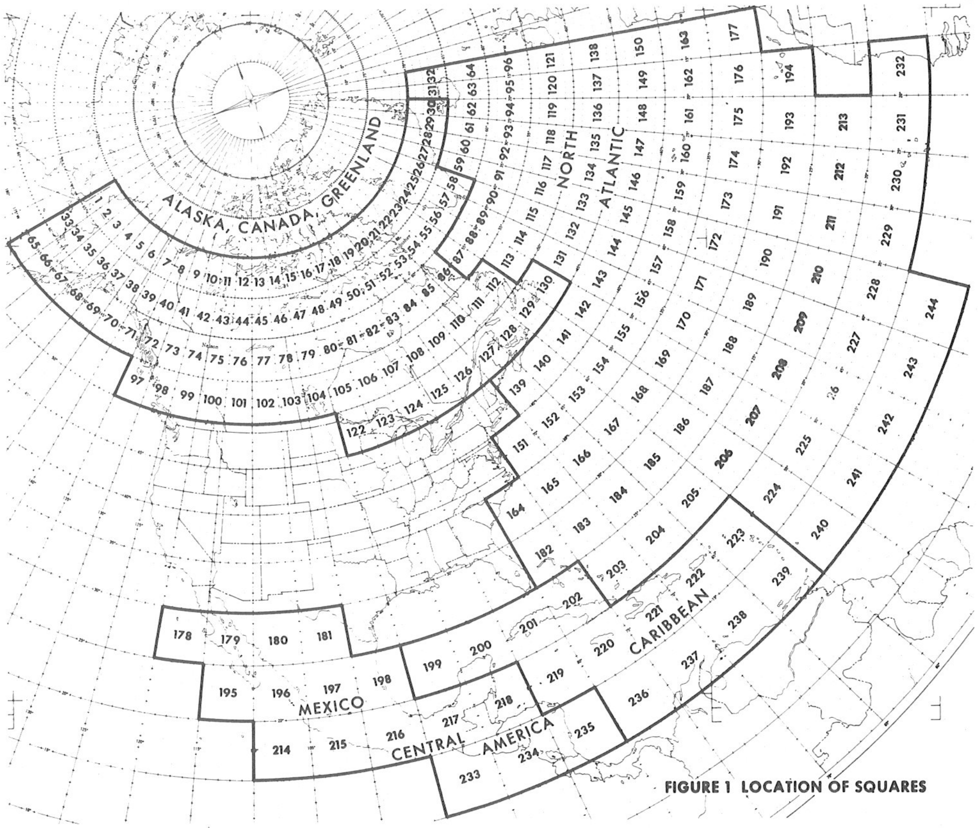

FIGURE 1 LOCATION OF SQUARES

The United States was responsible for analyzing data from the North Atlantic and Caribbean as well as North and Central America. Two previous reports have been prepared on the analysis of data over the conterminous 48 states (1, 2). The present report treats data over Alaska, Canada, Greenland, Mexico, Central America, the North Atlantic, and the Caribbean.

In the study of data over the conterminous 48 states, flight reports were tabulated by 2½-degree squares. However, the number of flights available for the present study did not warrant the use of 2½-degree squares, and the data were tabulated by 5-degree latitude-longitude squares. Figure 1 shows the location of these squares.

From the information on the data cards, it was possible to determine both the number of occurrences and non-occurrences of turbulence over each 5-degree square. Tabulations were made for each 12-hour period (centered at 0000 and 1200Z) of the total number of flights and the number each of reports of no turbulence, light, moderate, and severe turbulence encounters in each of three altitude layers over each 5-degree square. The altitude layers were: (A) below 30,000 feet, (B) 30,000 to 33,999 feet, and (C) 34,000 feet and above. Tabulations were also made of the total number and percentage of flights with moderate or greater turbulence encounters in each 5-degree square.

In this report, the term flight square refers to one flight over one 5-degree square. For example, a given flight crossing 4 squares would constitute a total of 4 flight squares, or 8 flights each crossing 5 squares would constitute a total of 40 flight squares.

The basic information used in analyzing the relationship of turbulence to meteorological parameters such as contour-height and temperature fields, jet streams, and isotachs, was obtained from 300-mb charts.

II. 9 - 14 DECEMBER 1964 DATA COLLECTION PERIOD

A. SUMMARY OF DECEMBER DATA

The distribution of the total number of flight squares, total number of occurrences of each turbulence intensity, and the probability or frequency of different intensities of turbulence are shown in Table I for each 12-hour period. The tabulation is shown for each of the three altitude layers and for the combined data in all three layers. Separate tabulations are given for (a) the North Atlantic, (b) Alaska, Canada, and Greenland (ACG), (c) the Caribbean, and (d) Mexico and Central America.

The overall probability of moderate or greater turbulence for the 5-day period was 6 percent over the North Atlantic, 5 percent over ACG, 1 percent over the Caribbean, and 10 percent over Mexico and Central America. The percentages varied considerably in the individual 12-hour time periods. The probability of moderate or greater turbulence varied from 0 to 19 percent over the North Atlantic and from 3 to 11 percent over ACG, with similar variability for no turbulence and for light or greater turbulence. Since the total number of flights over the Caribbean, Mexico, and Central America was quite small the results are not as significant as those over the other two regions.

TABLE I. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS 9 - 14 DECEMBER 1964

a. NORTH ATLANTIC

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
09-00 Z	92	75	8	9	0	82	18	10	0
-12	182	163	13	6	0	90	10	3	0
10-00	578	469	79	29	1	81	19	5	<1
-12	373	314	43	14	2	84	16	4	1
11-00	374	284	49	38	3	76	24	11	1
-12	448	385	31	27	5	86	14	7	1
12-00	360	305	29	24	2	85	15	7	1
-12	279	251	16	12	0	90	10	4	0
13-00	318	279	21	18	0	88	12	6	0
-12	197	155	28	14	0	79	21	7	0
14-00	152	133	10	9	0	88	12	6	0
TOTAL	3353	2813	327	200	13	84	16	6	<1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
09-00 Z	4	1	2	1	0	32	27	1	4	0	56	47	5	4	0
-12	19	15	4	0	0	73	66	6	1	0	90	82	3	5	0
10-00	110	92	14	4	0	196	153	36	6	1	272	224	29	19	0
-12	57	44	10	3	0	169	138	26	5	0	147	132	7	6	2
11-00	78	60	13	5	0	123	87	21	15	0	173	137	15	18	3
-12	64	57	6	1	0	186	157	13	16	0	198	171	12	10	5
12-00	36	29	4	3	0	137	118	11	8	0	187	158	14	13	2
-12	30	27	0	3	0	96	87	6	3	0	153	137	10	6	0
13-00	32	26	4	2	0	129	115	8	6	0	157	138	9	10	0
-12	16	12	1	3	0	87	70	12	5	0	94	73	15	6	0
14-00	16	13	2	1	0	22	17	3	2	0	114	103	5	6	0
TOTAL	462	376	60	26	0	1250	1035	143	71	1	1641	1402	124	103	12
PERCENT NONE	81					83					85				
≥L	19					17					15				
≥M	6					6					7				
S	0					<1					1				

TABLE I. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 9 - 14 DECEMBER 1964

b. ALASKA, CANADA AND GREENLAND

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
09-00 Z	81	71	10	0	0	88	12	0	0
-12	126	110	12	3	1	87	13	3	1
10-00	331	295	25	11	0	89	11	3	0
-12	156	140	12	4	0	90	10	3	0
11-00	265	229	29	7	0	86	14	3	0
-12	143	91	25	23	4	64	36	19	3
12-00	186	144	24	14	4	77	23	10	2
-12	103	91	8	3	1	88	12	4	1
13-00	196	163	19	14	0	83	17	7	0
-12	66	64	2	0	0	97	3	0	0
14-00	79	70	3	5	1	89	11	8	1
TOTAL	1732	1468	169	84	11	85	15	5	1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
09-00 Z	17	12	5	0	0	28	26	2	0	0	36	33	3	0	0
-12	35	23	9	2	1	27	25	2	0	0	64	62	1	1	0
10-00	105	93	4	8	0	99	87	12	0	0	127	115	9	3	0
-12	54	50	4	0	0	38	32	4	2	0	64	58	4	2	0
11-00	54	50	4	0	0	99	84	9	6	0	112	95	16	1	0
-12	17	11	3	3	0	40	20	11	8	1	86	60	11	12	3
12-00	30	23	3	4	0	49	33	12	4	0	107	88	9	6	4
-12	19	14	3	2	0	35	32	3	0	0	49	45	2	1	1
13-00	44	38	4	2	0	55	47	5	3	0	97	78	10	9	0
-12	8	6	2	0	0	35	35	0	0	0	23	23	0	0	0
14-00	24	19	1	3	1	12	11	1	0	0	43	40	1	2	0
TOTAL	407	339	42	24	2	517	432	61	23	1	808	697	66	37	8
PERCENT NONE	83					84					86				
≥L	17					16					14				
≥M	6					4					6				
S	<1					<1					1				

TABLE I. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS 9 - 14 DECEMBER 1964

c. CARIBBEAN

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCIES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
09-00 Z	1	1	0	0	0	100	0	0	0
-12	4	3	1	0	0	75	25	0	0
10-00	16	16	0	0	0	100	0	0	0
-12	13	12	1	0	0	92	8	0	0
11-00	14	12	2	0	0	86	14	0	0
-12	20	19	1	0	0	95	5	0	0
12-00	9	9	0	0	0	100	0	0	0
-12	4	4	0	0	0	100	0	0	0
13-00	12	11	0	1	0	92	8	8	0
-12	5	5	0	0	0	100	0	0	0
14-00	7	6	1	0	0	86	14	0	0
TOTAL	105	98	6	1	0	93	7	1	0

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURENCES OF INTENSITY NONE	L	M	S
09-00 Z	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
-12	1	1	0	0	0	3	2	1	0	0	0	0	0	0	0
10-00	11	11	0	0	0	5	5	0	0	0	0	0	0	0	0
-12	8	8	0	0	0	5	4	1	0	0	0	0	0	0	0
11-00	6	6	0	0	0	5	4	1	0	0	3	2	1	0	0
-12	5	5	0	0	0	10	9	1	0	0	5	5	0	0	0
12-00	2	2	0	0	0	5	5	0	0	0	2	2	0	0	0
-12	0	0	0	0	0	3	3	0	0	0	1	1	0	0	0
13-00	3	3	0	0	0	7	7	0	0	0	2	1	0	1	0
-12	0	0	0	0	0	2	2	0	0	0	3	3	0	0	0
14-00	4	3	1	0	0	0	0	0	0	0	3	3	0	0	0
TOTAL	41	40	1	0	0	45	41	4	0	0	19	17	1	1	0
PERCENT NONE	98					91					89				
≥L	2					9					11				
≥M	0					0					5				
S	0					0					0				

TABLE I. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 9 - 14 DECEMBER 1964

d. MEXICO AND CENTRAL AMERICA

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCIES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
09-00 Z	1	1	0	0	0	100	0	0	0
-12	7	5	2	0	0	71	29	0	0
10-00	11	7	2	2	0	64	36	18	0
-12	3	2	0	1	0	67	33	33	0
11-00	11	7	3	1	0	64	36	9	0
-12	1	1	0	0	0	100	0	0	0
12-00	3	3	0	0	0	100	0	0	0
-12	6	5	0	1	0	83	17	17	0
13-00	10	9	0	1	0	90	10	10	0
-12	2	2	0	0	0	100	0	0	0
14-00	7	6	1	0	0	86	14	0	0
TOTAL	62	48	8	6	0	77	23	10	0

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
09-00 Z	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
-12	0	0	0	0	0	6	4	2	0	0	1	1	0	0	0
10-00	5	5	0	0	0	1	1	0	0	0	5	1	2	2	0
-12	0	0	0	0	0	1	0	0	1	0	2	2	0	0	0
11-00	1	0	1	0	0	6	4	2	0	0	4	3	0	1	0
-12	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
12-00	0	0	0	0	0	2	2	0	0	0	1	1	0	0	0
-12	0	0	0	0	0	2	2	0	0	0	4	3	0	1	0
13-00	0	0	0	0	0	2	2	0	0	0	8	7	0	1	0
-12	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
14-00	1	1	0	0	0	0	0	0	0	0	6	5	1	0	0
TOTAL	7	6	1	0	0	22	17	4	1	0	33	25	3	5	0
PERCENT NONE	86					77					76				
≥L	14					23					24				
≥M	0					5					15				
S	0					0					0				

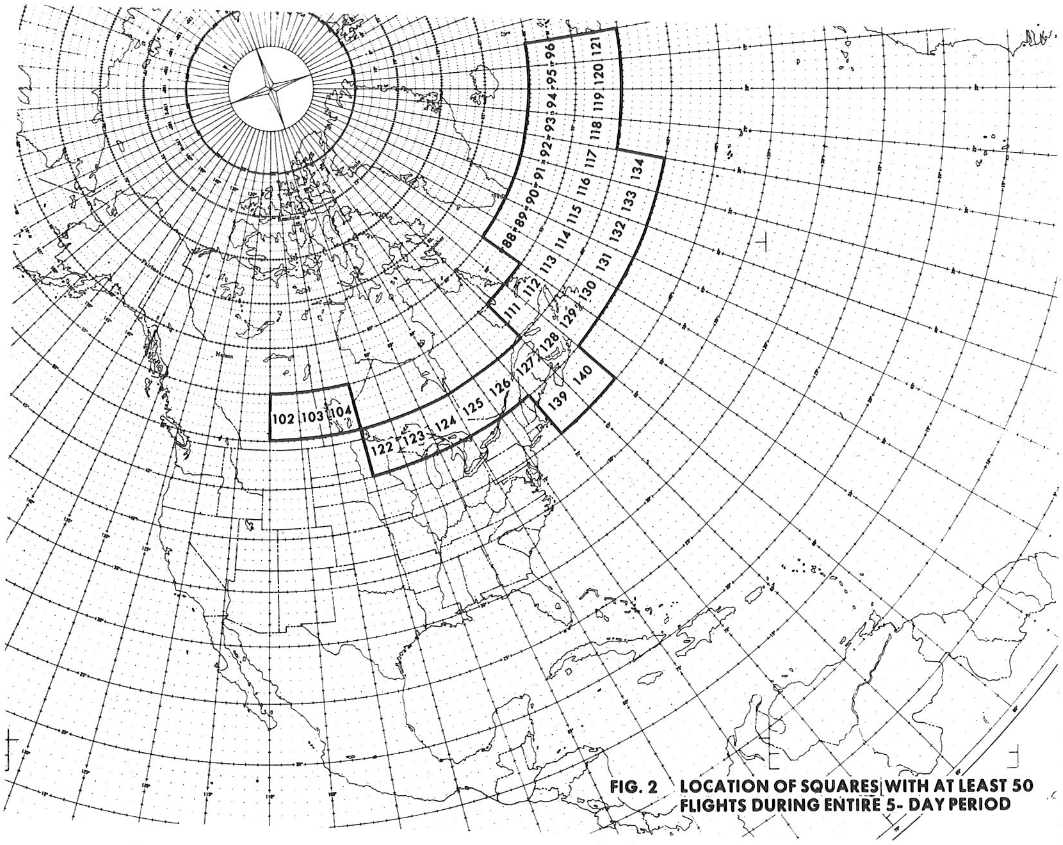

FIG. 2 LOCATION OF SQUARES WITH AT LEAST 50 FLIGHTS DURING ENTIRE 5-DAY PERIOD

The probability of no turbulence increased slightly, the probability of light or greater turbulence decreased slightly, and the probability of moderate or greater turbulence increased slightly with altitude over both the North Atlantic and ACG. The probability of severe turbulence was higher in the top layer than in the two lower layers.

The location, altitude, and time of all severe turbulence occurrences are shown in Table II. It is interesting to note that 20 of the 24 occurrences were in the layer of 34,000 ft. and above (C), and only 2 occurrences were in each of the two lower layers (A, B). Also, 18 of the 24 occurrences were in the three 12-hour time periods centered at 11-0000Z, 11-1200Z, and 12-0000Z.

A summarization of the 5-day total occurrences in individual 5-degree squares indicated that many squares had no flights and a large number had only a few flights. Of the total of 244 squares, there were only 38 squares each having at least 50 flights for the entire period. The locations of these squares, shown in Fig. 2, coincide with major international air routes.

TABLE II. LOCATION OF SEVERE TURBULENCE OCCURRENCES 9-14 December 1964

NORTH ATLANTIC			ALASKA, CANADA, GREENLAND		
DATE-TIME	SQUARE	LAYER	DATE-TIME	SQUARE	LAYER
10-00Z	139	B	09-12Z	129	A
10-12	119	C	11-12	126	B
10-12	120	C	11-12	127	C
11-00	115	C	11-12	127	C
11-00	116	C	11-12	128	C
11-00	116	C	12-00	111	C
11-12	93	C	12-00	127	C
11-12	94	C	12-00	128	C
11-12	132	C	12-00	128	C
11-12	133	C	12-12	128	C
11-12	140	C	14-00	125	A
12-00	118	C			
12-00	133	C			

None were reported over the Caribbean, Mexico, and Central America.

B. METEOROLOGICAL ANALYSIS

In the two previous reports dealing with data over the conterminous 48 states (1, 2), considerable analysis of both large-scale circulation patterns and more detailed local meteorological data was made. Correlations were obtained between both turbulence occurrences and probabilities of moderate or greater turbulence and such meteorological factors as upper level troughs, jet streams, isotach patterns, vertical wind shear, wind speed, Richardson Number, stability, deformation, etc.

In the present paper dealing with the remainder of the area, it was not possible to make similar analyses due to the smaller number of flights per given area and much sparser upper-air data coverage. Vertical wind shear, which had been found most effective, could not be used due to the lack of detailed data on the vertical structure of the atmosphere. It was necessary to use horizontal wind shear instead.

Figure 3 shows the mean 300-mb circulation pattern, including contour-heights and isotherms, and the probability of moderate or greater turbulence at each square for the entire 5-day period. Squares with at least 10 percent probability of moderate or greater turbulence are outlined. The results are in agreement with those found over the conterminous 48 states (1). Most of the higher probability squares were located along and to the east of the mean trough and near a region of high contour gradients. Several other high probability squares were scattered over the chart. One such area, located just east of Vancouver, was probably associated with mountain wave activity over the coastal and Rocky Mountains.

The sequence of upper level circulation patterns during this 5-day period, as illustrated by the 1200Z 300-mb charts (Figures 4 to 8), was quite significant for variations in turbulence. These charts include contour-height lines, isotherms, location of jet streams, and the probability of moderate or greater turbulence at each square. Squares with at least 10 percent probability of moderate or greater turbulence are outlined, and squares with severe turbulence are marked.

The start of the 5-day period was characterized by three major troughs: one over the western United States, one along the east coast of the United States, and one over western Europe. A parallel double jet structure was associated with nearly zonal flow across the Atlantic, especially east of 50°W longitude. These features are illustrated on the 9-1200Z 300-mb chart. (Fig. 4)

The troughs over the western United States and off the east coast moved eastward and deepened during the next 24 hours, as shown on the 10-1200Z 300 mb chart (Fig. 5) with the flow becoming more meridional over the United States and the western Atlantic. Cold air advection was indicated to the west of the Atlantic trough. The eastward displacement and deepening of the troughs continued during the next 24 hours, as can be seen on the 11-1200Z 300-mb chart (Fig. 6). Both troughs had become quite sharp, with increased amplitude and greatly increased curvature of flow around them. The double jet structure had consolidated into one stronger jet across the Atlantic with increased contour gradients. The temperature and contour-height fields were more nearly in phase, and the trough in the Atlantic appeared as a cold trough.

During the next 24 hours, the troughs over the United States and the Atlantic started filling with a decided decrease in curvature of the flow around them and the high pressure ridge in the western Atlantic, as evident on the 12-1200Z 300-mb chart (Fig. 7). The amplitude of the systems had decreased, and the trough over United States had become less sharp. By the end of the 5-day period, as can be seen on the 13-1200Z 300-mb chart (Fig. 8), there was a continuing decrease in amplitude and curvature of the flow patterns. The flow to the north of 40°N latitude was more nearly zonal across the Atlantic, and the Atlantic trough was reduced to a warm cut-off low south of 40°N latitude.

It is interesting to note that the most turbulent periods were the three 12-hour periods centered at 11-0000, 11-1200, and 12-0000Z. These were the charts with the sharp troughs and ridges with large amplitude and sharp curvature of flow around these systems.

Figures 9-19 are the 300-mb charts showing the jet streams and isotachs along with the number of flights and the number of moderate or greater turbulence occurrences for the 12-hour period centered at these map times. Squares with at least 10 percent probability of moderate or greater turbulence are outlined, and squares with severe turbulence are marked.

On the chart for 9-0000Z (Fig. 9) there was little turbulence and only a few 10 percent squares. These squares were mostly located along the double jet structure in the eastern Atlantic between the two 125-knot isotachs. The other scattered turbulence reports were in the Central Atlantic well to the south of the high wind speeds, strong wind shear zones, and large contour gradients.

Most of the turbulence in the next period, 9-1200Z (Figures 4 and 10) was concentrated between the 125-knot isotachs on the two parallel jet streams. Two reports of turbulence were located in the fairly sharp anticyclonic flow north of Lake Superior. The amount of turbulence in the next period, 10-0000Z (Fig. 11), increased with intensification of the troughs and ridges and increased curvature of the flow patterns. The greatest concentration was in the anticyclonic flow patterns and near the 150-knot isotach in the Atlantic. Considerable turbulence was located in the deepening trough in the western Atlantic, including one report of severe turbulence just west of the trough. Some turbulence occurred just north of the jet, in the strong wind flow across the coastal mountains along the United States-Canada border.

Most of the turbulence in the next period, 10-1200Z (Figures 5 and 12), occurred in the increasing anticyclonic curvature near the Great Lakes and eastern Atlantic. Two reports of severe turbulence were present in the eastern Atlantic.

Turbulence occurrences for the 11-0000Z period (Fig. 13) were confined largely to anticyclonically curved flow patterns around the ridge in southeast Canada and the eastern Atlantic. Most of the latter concentration was between the two jets and associated with the 100 and 125-knot isotachs. Two reports of severe turbulence were found near the 125-knot isotach on the northern jet.

Turbulence was most pronounced during the 12-hour period centered at 11-1200Z (Figures 6 and 14). The double jet structure had consolidated into one stronger jet with two 150-knot isotachs along its axis. One area of turbulence was in the region of the sharp anticyclonic curvature around the high pressure ridge in southeast Canada and ahead of the 150-knot isotach. The other area of turbulence was associated with the 125 and 150-knot isotachs in the sharp anticyclonic curvature over the eastern Atlantic with increasing wind speed and horizontal wind shear. Nine reports of severe turbulence were located in these two areas.

During the 12-hour period illustrated by the 12-0000Z chart (Fig. 15), the strong winds, large horizontal wind shear, and sharp curvature were still present. Turbulence was confined to two main regions. One was along the jet in the eastern Atlantic near the 125-knot isotach. The other was in the sharp anticyclonic curvature of flow around the high pressure ridge in extreme southeast Canada. Six reports of severe turbulence were made in this period.

By 12-1200Z (Figures 7 and 16), the troughs and ridges had started to weaken with a gradual decrease in the curvature of the flow patterns. At the same time, the amount of turbulence decreased during this period. Most of the turbulence was concentrated in the circulation around the ridge and near the 125-knot isotach over the extreme eastern Atlantic. The systems continued weakening during the next 12 hours, as illustrated by the 13-0000Z chart (Fig. 17). Some turbulence was reported along the jet which was now oriented largely west to east across the western Atlantic. A few reports of turbulence were associated with the 100-knot isotach along the double jet eastward from New England. Some turbulence was associated with the 125-knot isotach over the eastern Atlantic. A jet from Alaska into northwest United States had intensified with a 125-knot isotach present. A few occurrences of turbulence were located to the left of this jet.

During the next 12-hour period, as illustrated by the 13-1200Z chart (Figures 8 and 18), turbulence had decreased except for an area over the eastern Atlantic. Some turbulence was reported in convergence zones between the two jets near the 100-knot isotach and a few reports near the 125-knot isotach along the major jet. By the end of the 5-day period, as shown in the 14-0000Z chart (Fig. 19), turbulence had decreased to scattered single reports. The greatest concentration was in a divergence zone off the New England coast. A small area with two reports was located near a 125-knot isotach over the Great Lakes, and another was associated with the 125-knot isotach and strong flow across the Canadian Rockies.

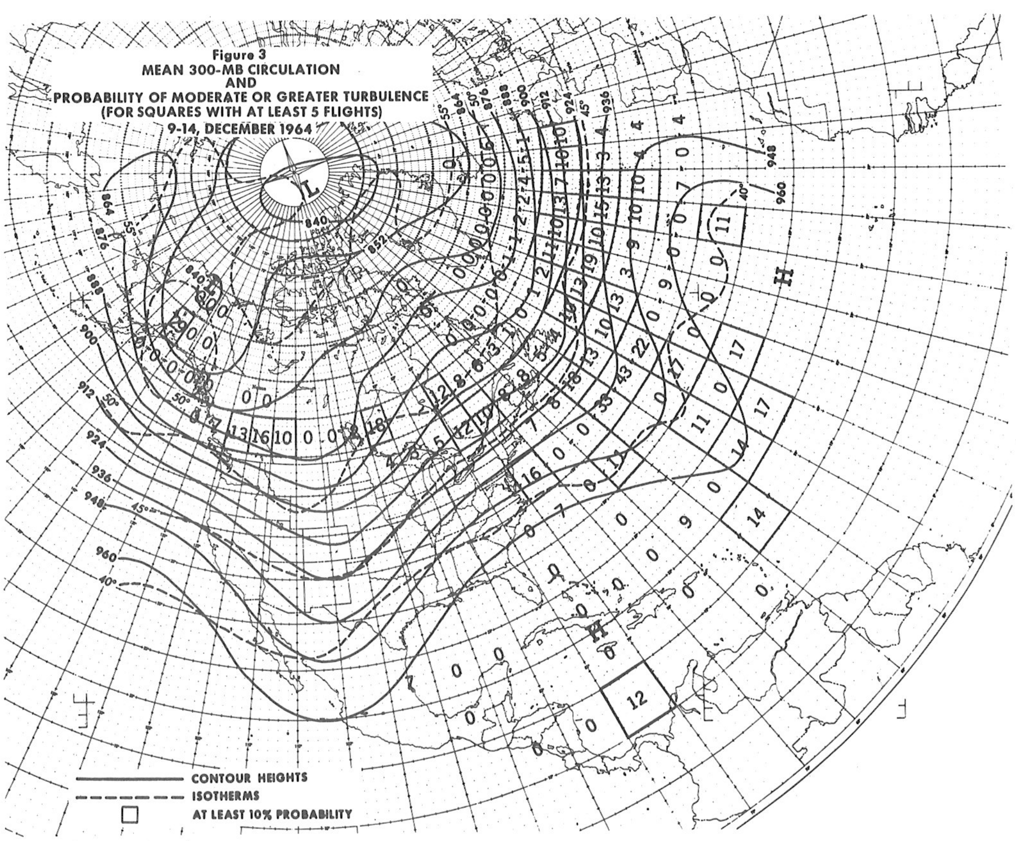

Figure 3
MEAN 300-MB CIRCULATION
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
(FOR SQUARES WITH AT LEAST 5 FLIGHTS)
9-14, DECEMBER 1964

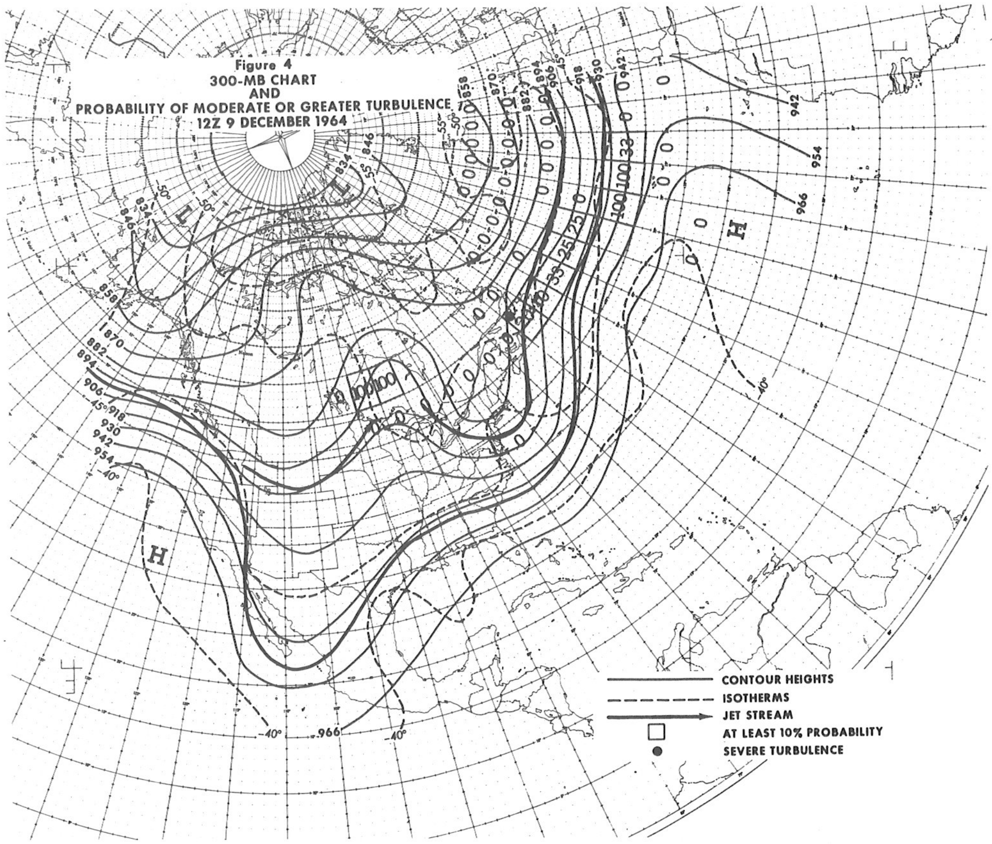
Figure 4
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
12Z 9 DECEMBER 1964
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

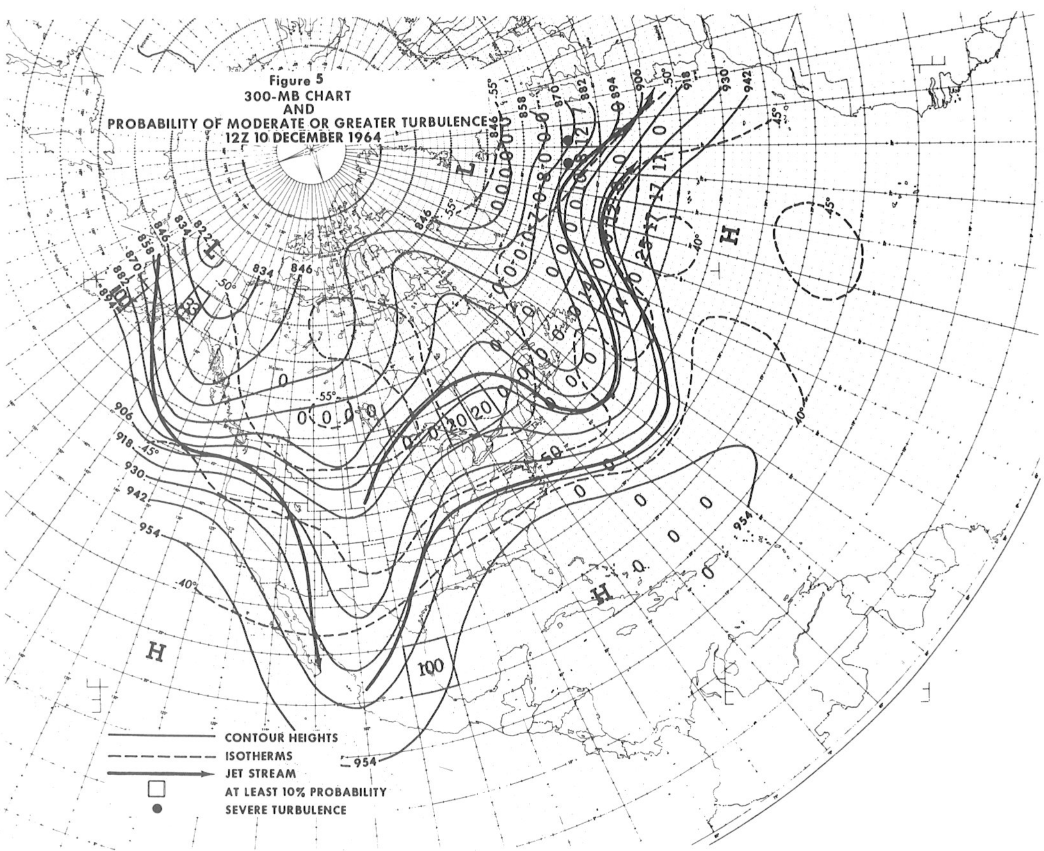
Figure 5
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
12Z 10 DECEMBER 1964
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

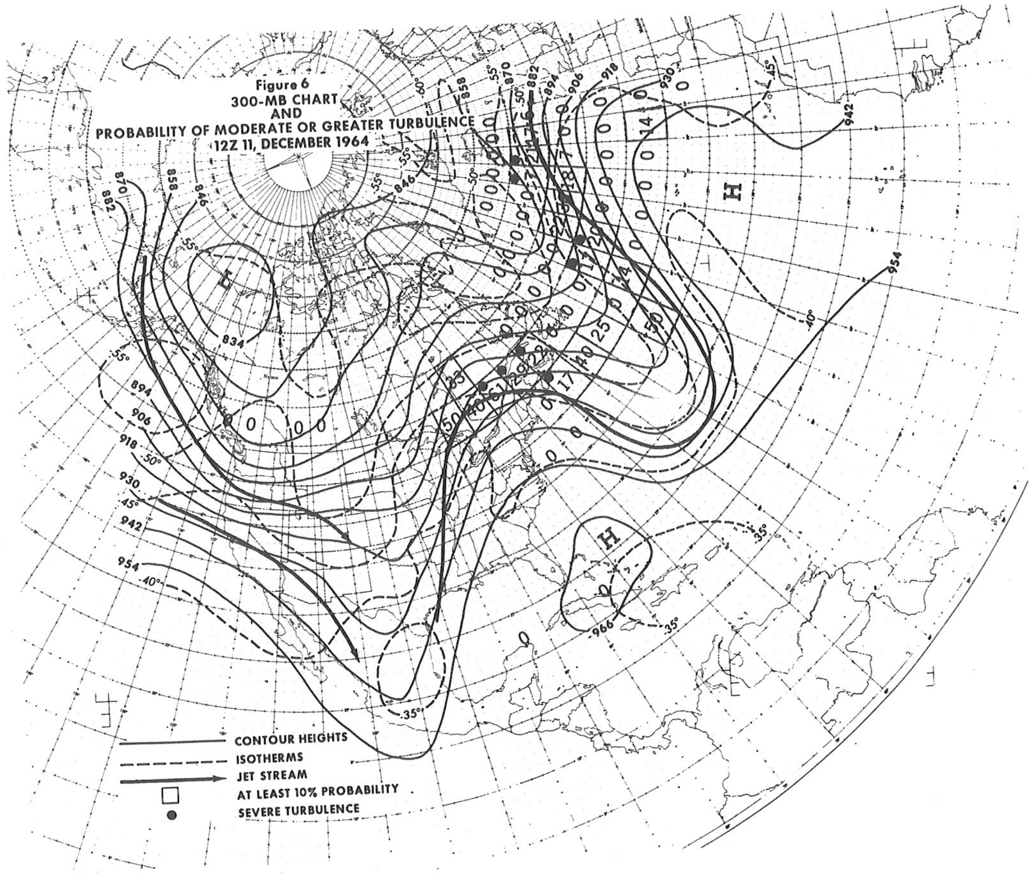
Figure 6
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
12Z 11, DECEMBER 1964
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

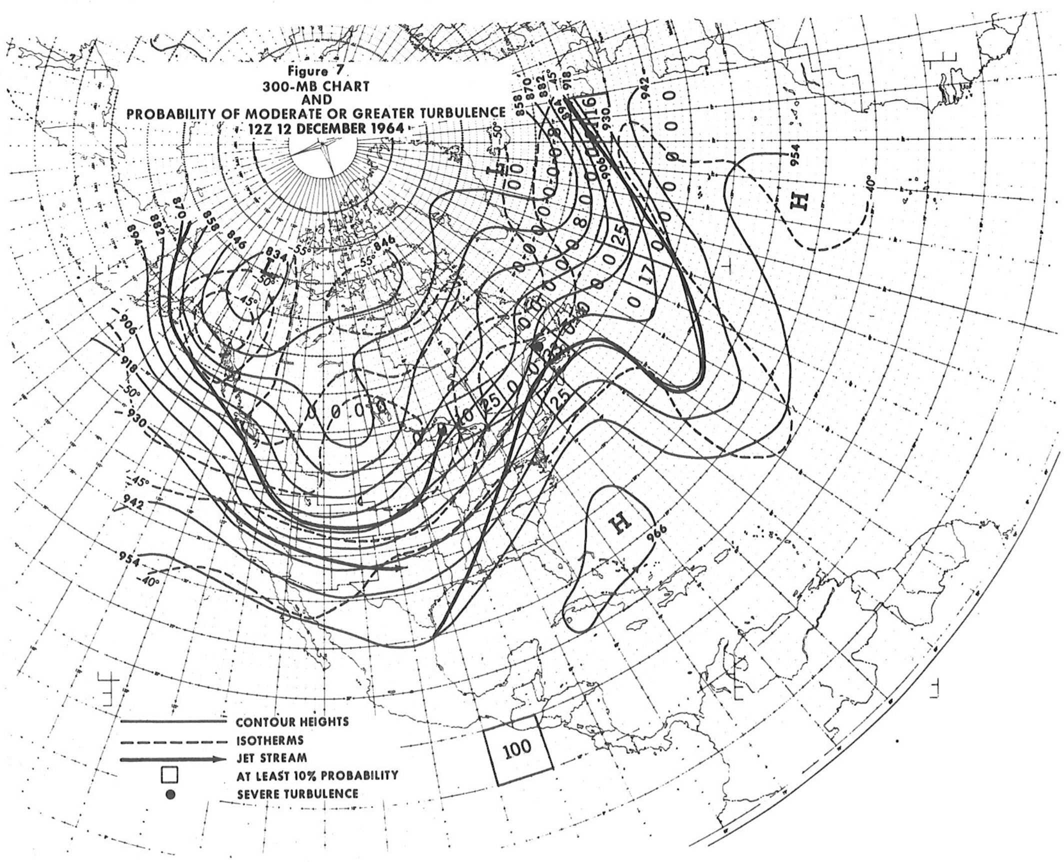
Figure 7
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
12Z 12 DECEMBER 1964
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE
100

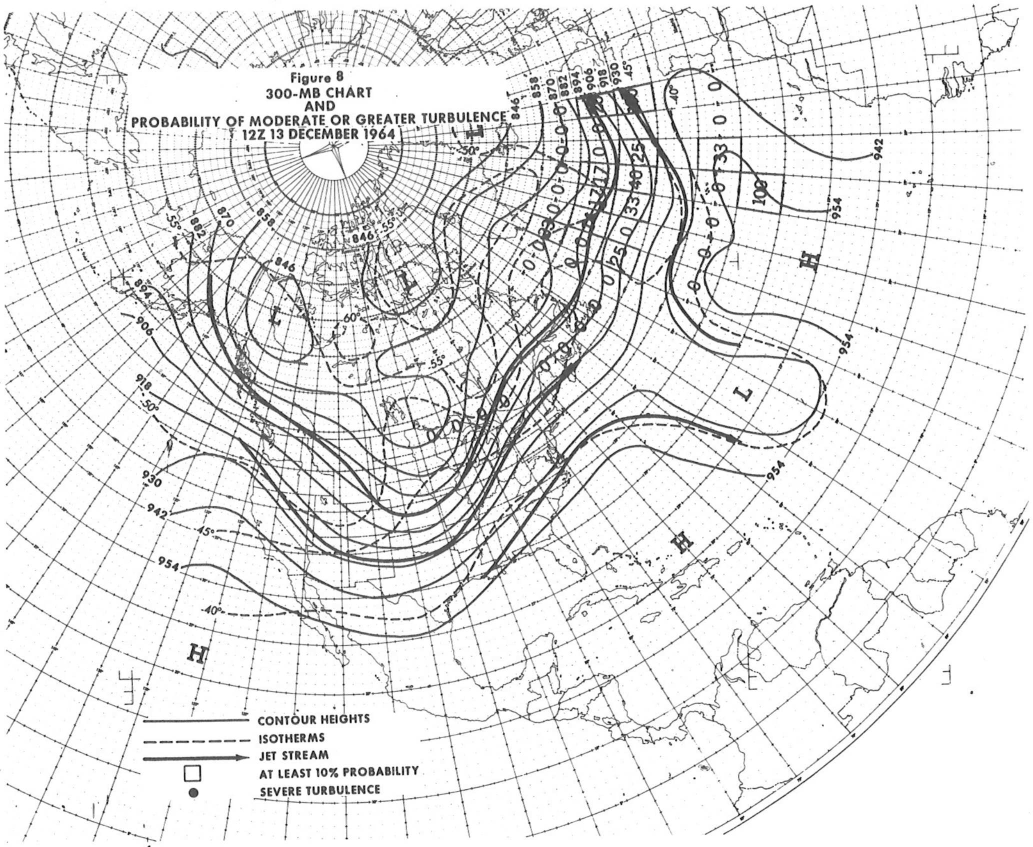
Figure 8
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
12Z 13 DECEMBER 1964
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

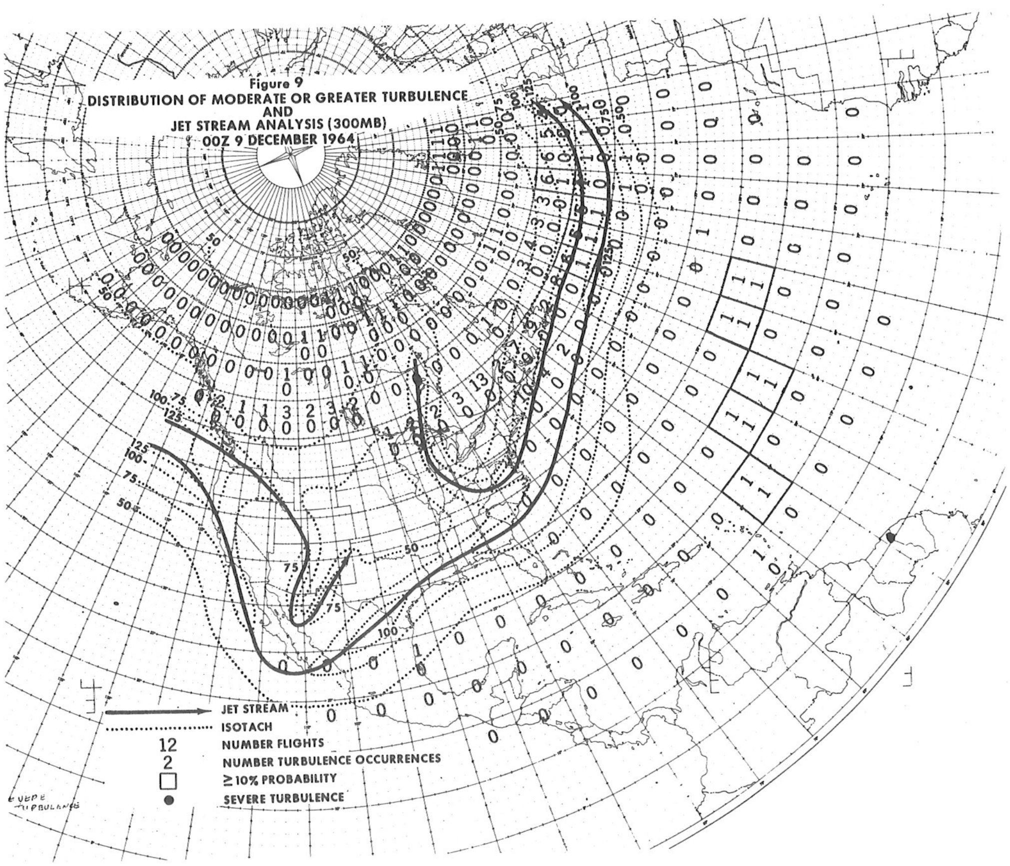
Figure 9
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 9 DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

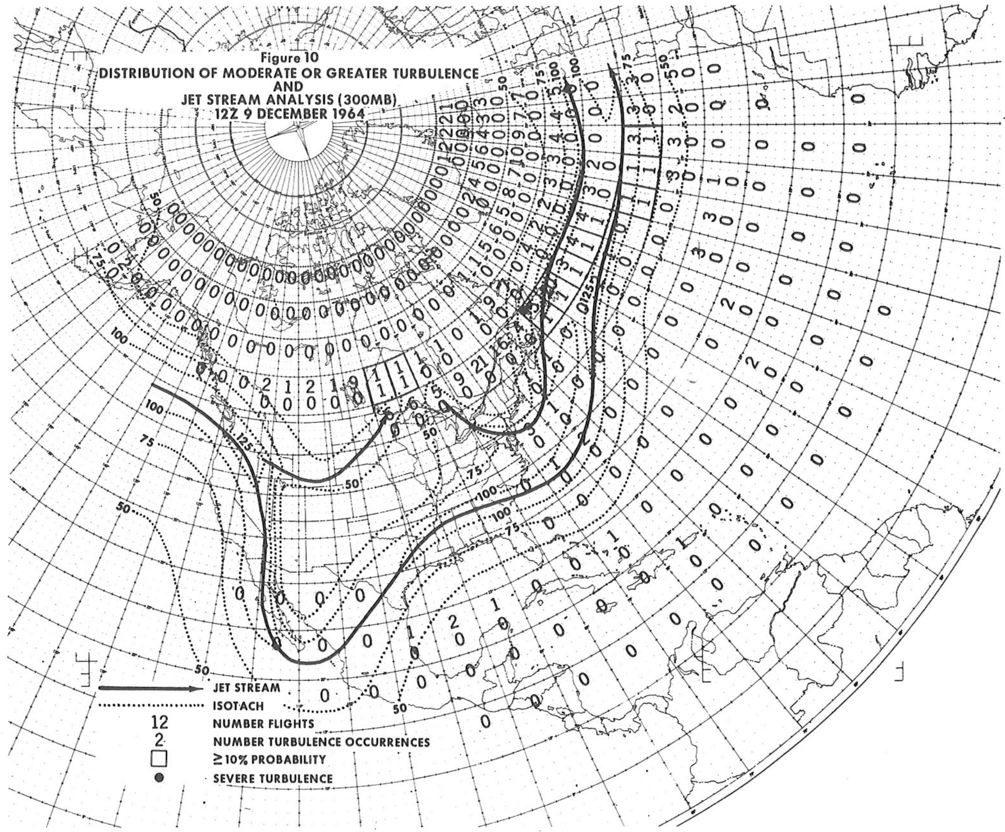

Figure 10
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 9 DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

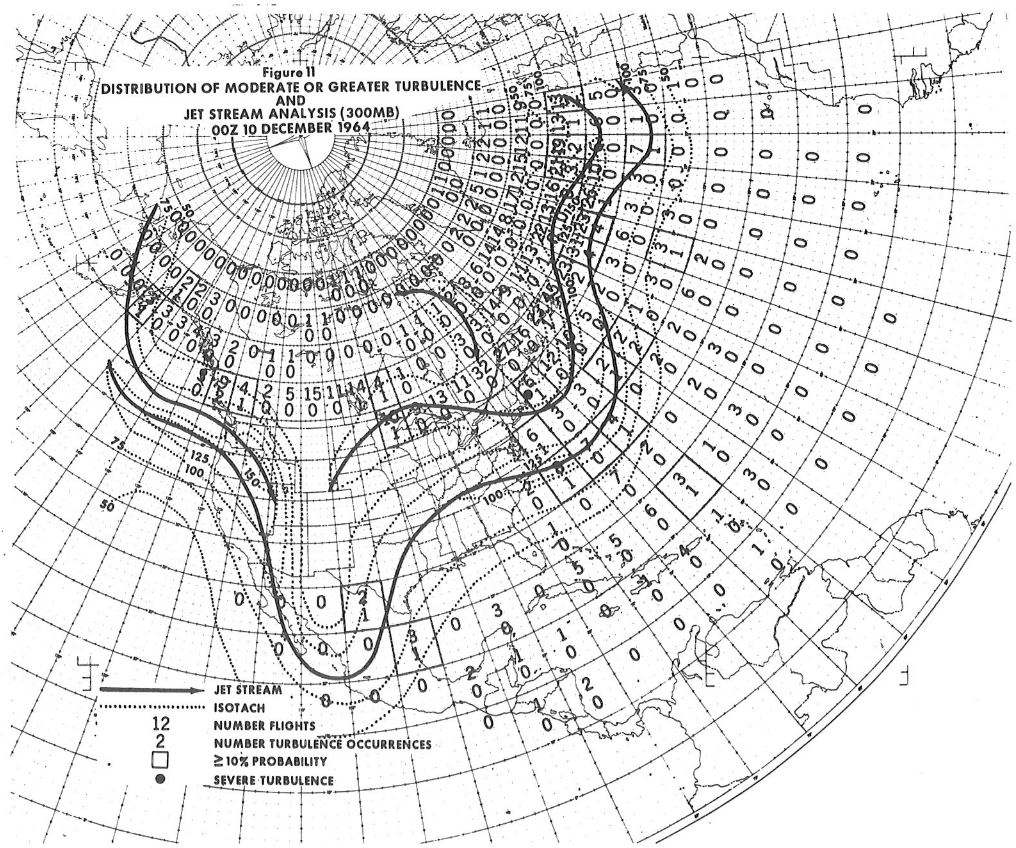

Figure 11
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 10 DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

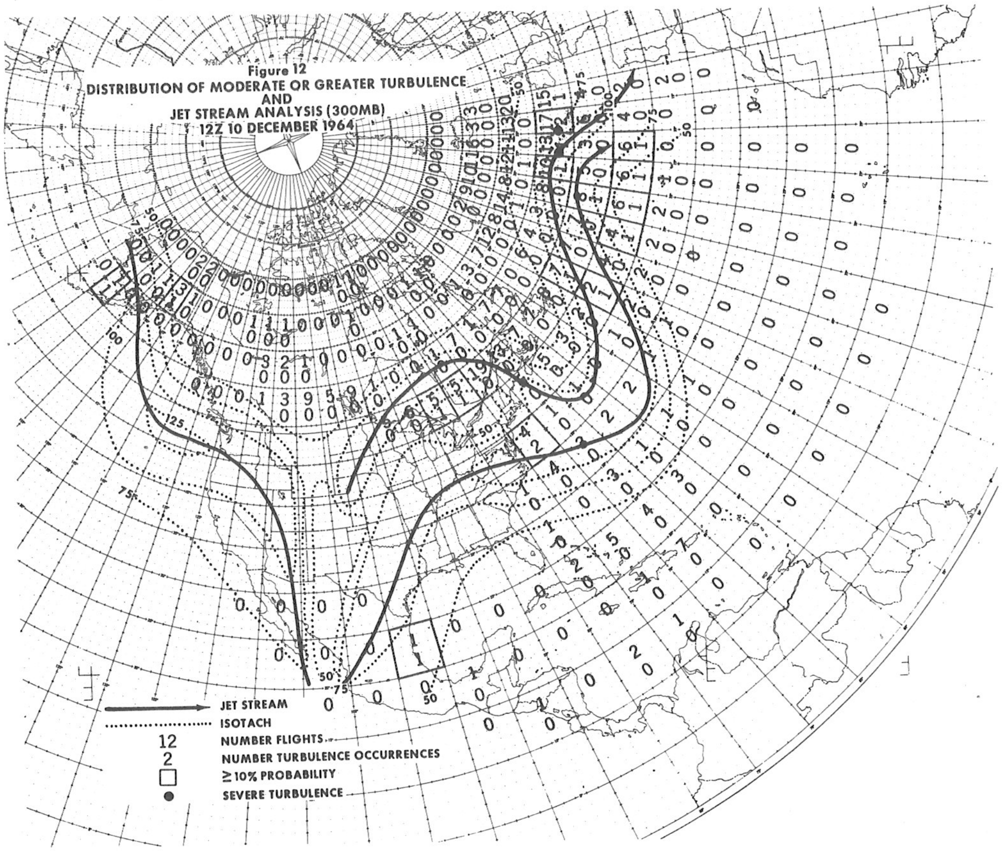
Figure 12
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 10 DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

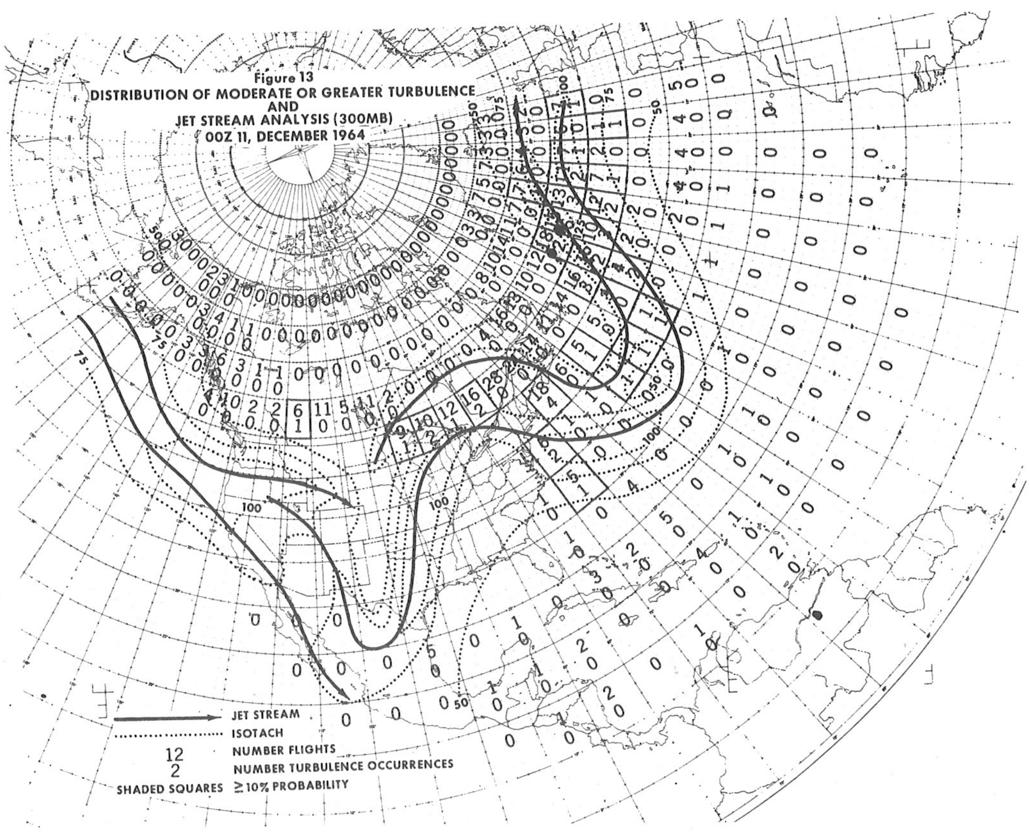
Figure 13
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 11, DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
SHADED SQUARES ≥10% PROBABILITY

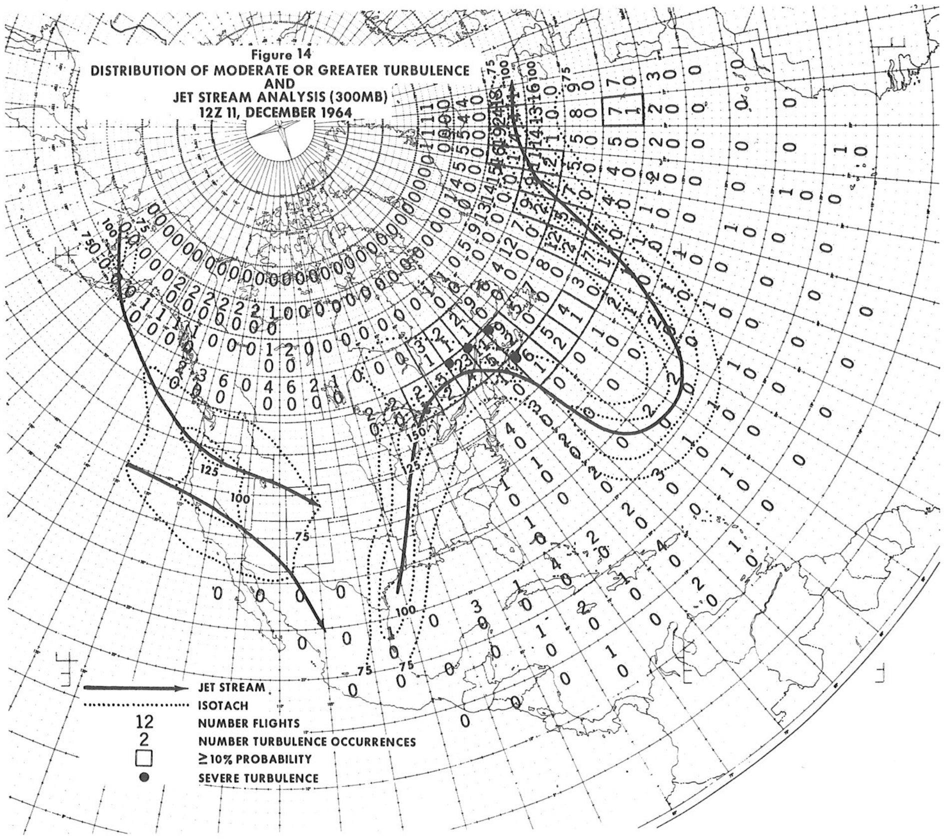
Figure 14
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 11, DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

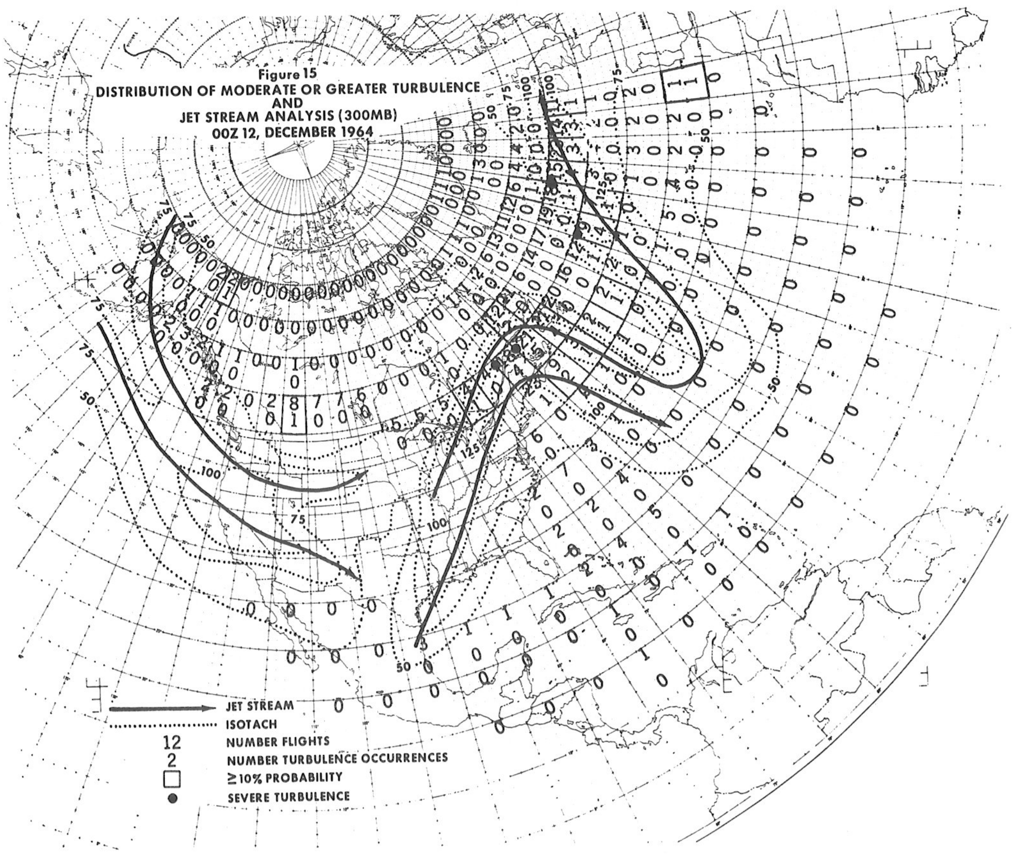
Figure 15
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 12, DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

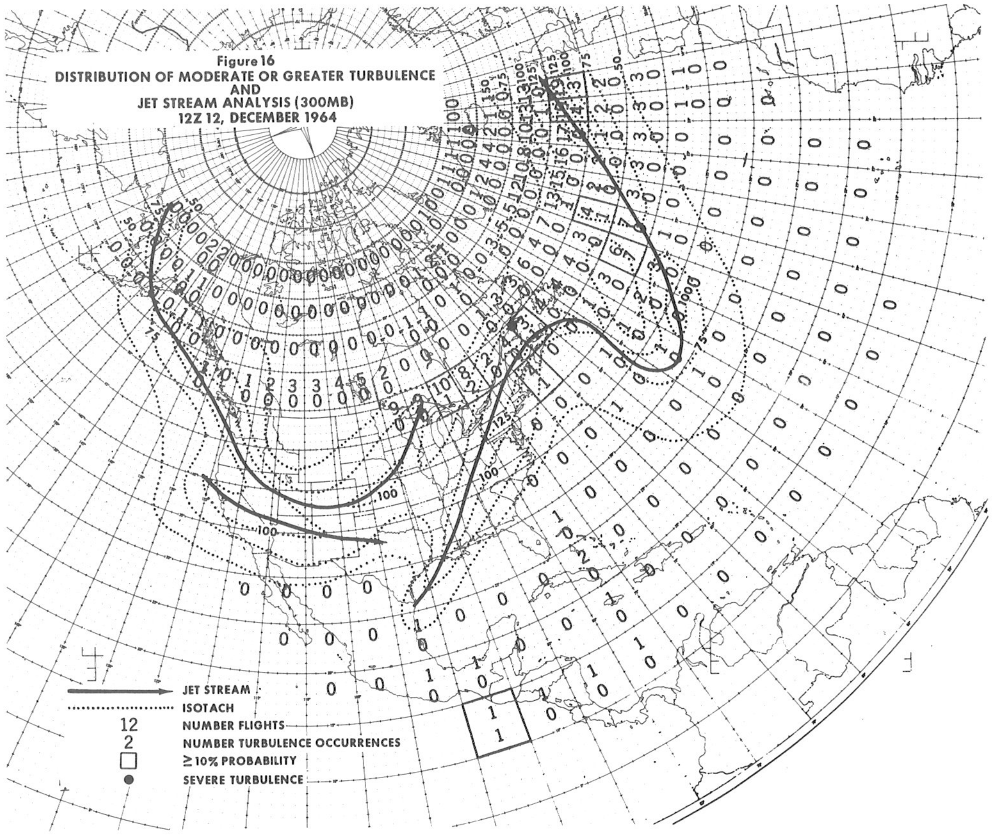
Figure 16
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 12, DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

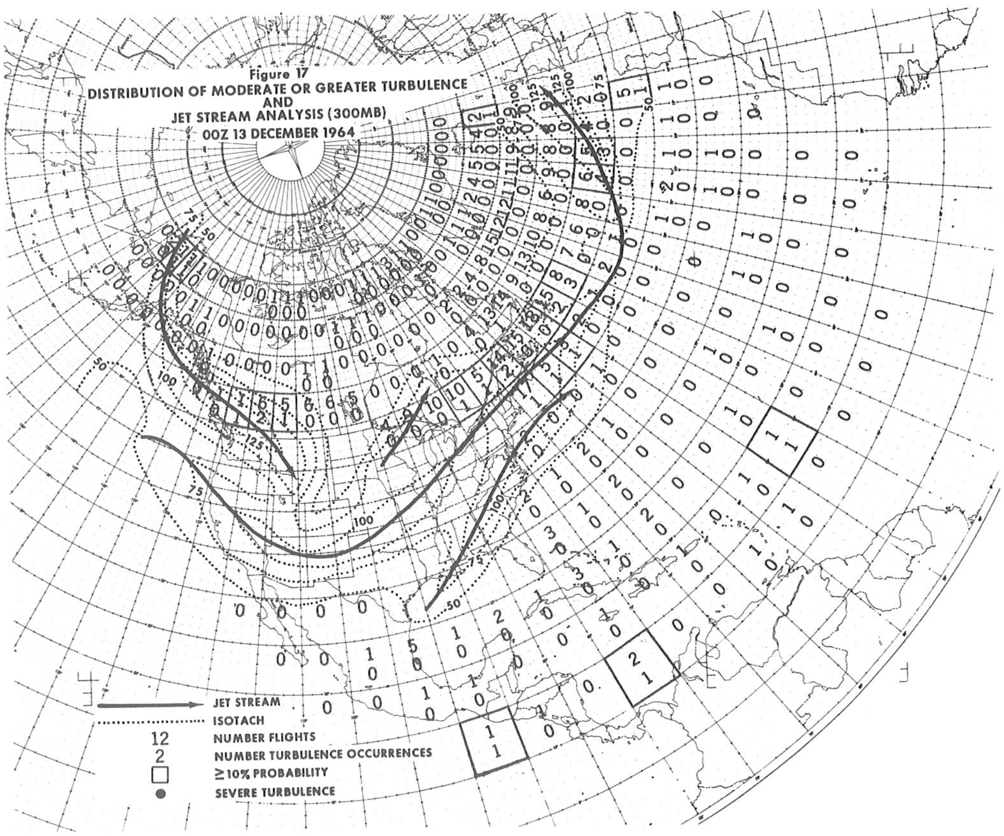
Figure 17
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 13 DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

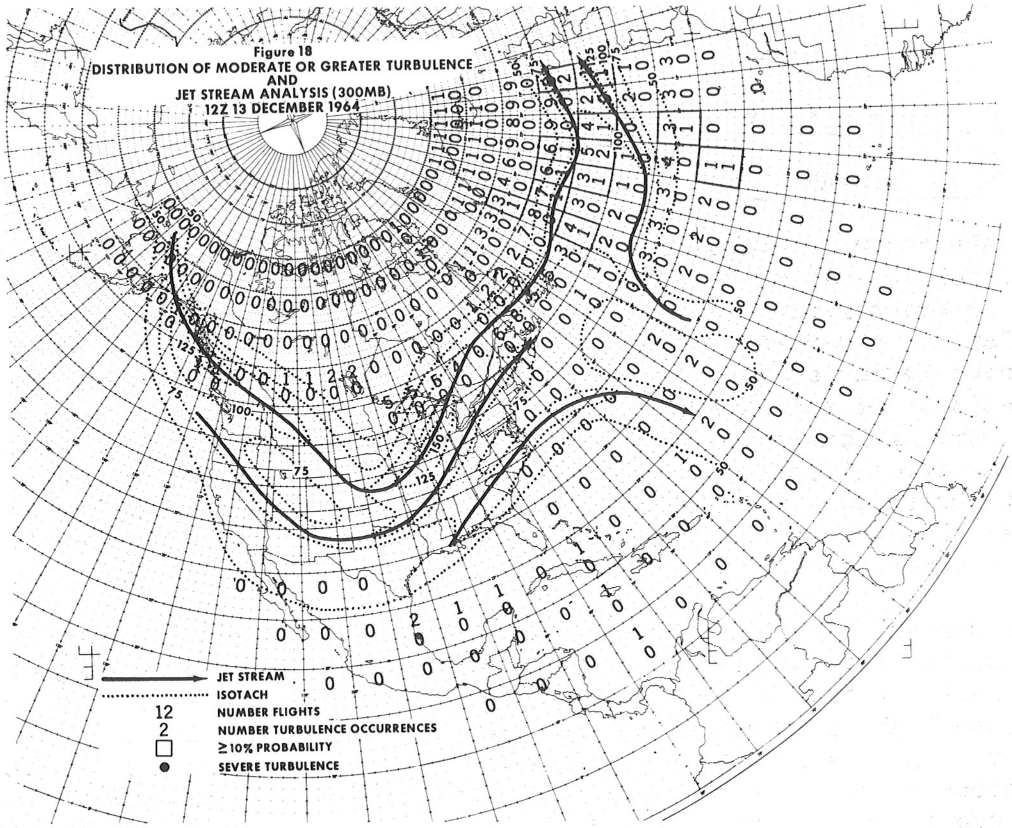
Figure 18
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 13 DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

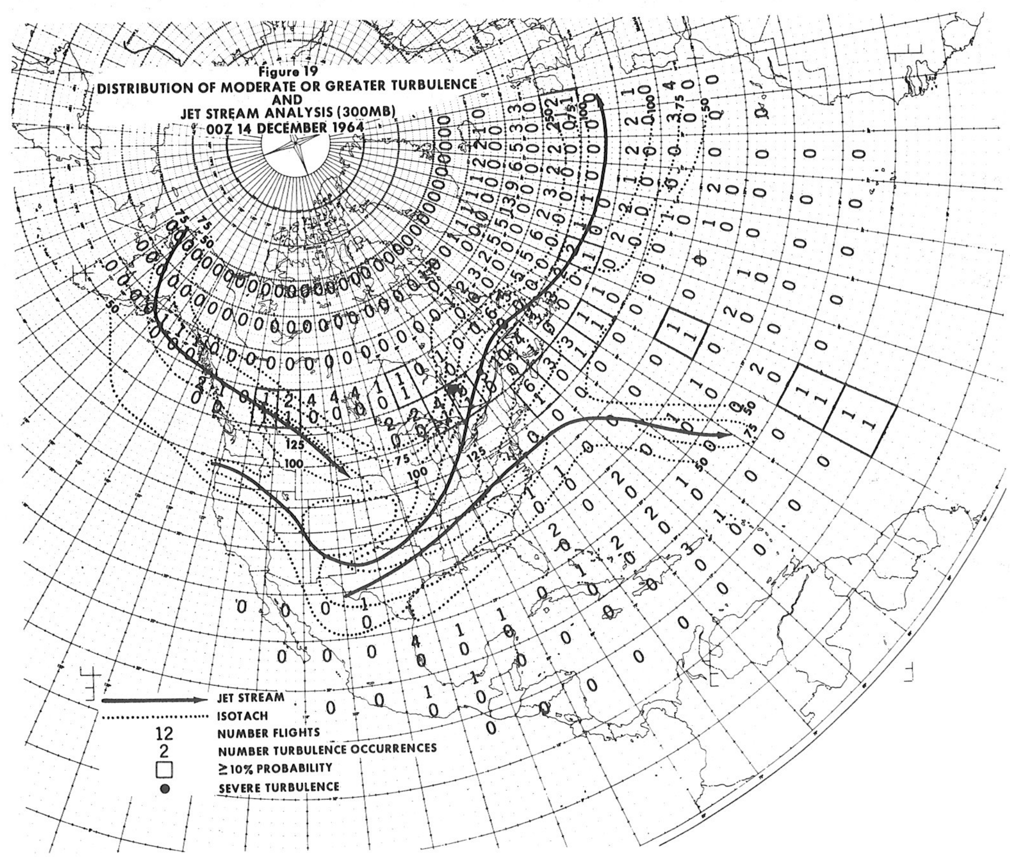
Figure 19
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 14 DECEMBER 1964
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

III. 10-15 MARCH 1965 DATA COLLECTION PERIOD

A. SUMMARY OF MARCH DATA

A tabulation of turbulence data for each 12-hour period is shown in Table III for 10 - 15 March 1965. The overall probability or frequency of moderate or greater turbulence for the entire period was 6 percent over the North Atlantic, 4 percent over ACG, 3 percent over the Caribbean, and 0 percent over Mexico and Central America. In the individual 12-hour periods, the probability of moderate or greater turbulence varied from 1 to 11 percent over the North Atlantic and from 0 to 9 percent over ACG. Similar variability was evident in the probabilities of no turbulence and of light or greater turbulence. As in December, the total number of flights was quite small over the Caribbean, Mexico, and Central America, and the percentages over these areas were not as reliable as those over the other two areas.

The percent of no turbulence increased and the percent of both light or greater and moderate or greater turbulence decreased with increasing altitude over the North Atlantic. The percent of no turbulence decreased and the percent of both light or greater and moderate or greater turbulence increased in layer B over layer A for the ACG region. However, the percent of no turbulence increased and the percent of both light or greater and moderate or greater turbulence decreased decidedly in layer C over the values in both of the lower layers for the ACG region, as was the case for the North Atlantic.

The location, time, and altitude of all severe turbulence occurrences are shown in Table IV, which indicated only one occurrence in layer A, five in layer B, and six in layer C. Eight of the twelve occurrences were reported in the two 12-hour periods centered at 11-0000Z and 12-0000Z. The other four reports were scattered in the 13-1200, 14-0000, and 14-1200Z periods.

Only 31 squares had a total of at least 40 flights each for the entire 5-day period.

B. METEOROLOGICAL ANALYSIS

The mean circulation pattern at the 300-mb level for the 5-day period is shown in Figure 20, along with isotherms and the probability of moderate or greater turbulence at each square. The squares with at least 10 percent probability of moderate or greater turbulence were concentrated in the mean trough off the east coast of United States and Canada and in the region of the greatest contour gradient across the Atlantic to the east of the trough. This agrees with the results for December (Fig. 3).

TABLE III. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 10 - 15 MARCH 1965

a. NORTH ATLANTIC

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY				PERCENT WITH			
		NONE	L	M	S	NONE	≥L	≥M	S
10-00 Z	120	110	6	4	0	92	8	3	0
-12	265	233	17	15	0	88	12	6	0
11-00	275	240	21	11	3	87	13	5	1
-12	339	320	16	3	0	94	6	1	0
12-00	256	215	18	21	2	84	16	8	1
-12	271	236	22	13	0	87	13	5	0
13-00	273	210	32	31	0	77	23	11	0
-12	251	201	32	17	1	80	20	7	<1
14-00	203	175	18	9	1	86	14	5	<1
-12	182	168	6	7	1	92	8	4	1
15-00	98	88	7	3	0	90	10	3	0
TOTAL	2533	2196	195	134	8	87	13	6	<1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	A NUMBER OCCURRENCES OF INTENSITY				B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	B NUMBER OCCURRENCES OF INTENSITY				C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	C NUMBER OCCURRENCES OF INTENSITY			
		NONE	L	M	S		NONE	L	M	S		NONE	L	M	S
10-00 Z	9	9	0	0	0	76	68	4	4	0	35	33	2	0	0
-12	36	23	6	7	0	107	99	5	3	0	122	111	6	5	0
11-00	50	43	6	1	0	110	88	11	8	3	115	109	4	2	0
-12	52	46	6	0	0	152	142	8	2	0	135	132	2	1	0
12-00	35	30	1	4	0	117	94	9	14	0	104	91	8	3	2
-12	49	46	3	0	0	123	97	17	9	0	99	93	2	4	0
13-00	47	33	8	6	0	117	88	16	13	0	109	89	8	12	0
-12	27	16	5	6	0	124	96	19	8	1	100	89	8	3	0
14-00	19	15	0	4	0	128	109	15	4	0	56	51	3	1	1
-12	41	36	2	2	1	76	72	2	2	0	65	60	2	3	0
15-00	15	13	1	1	0	40	40	0	0	0	43	35	6	2	0
TOTAL	380	310	38	31	1	1170	993	106	67	4	983	893	51	36	3
PERCENT NONE	82					85					91				
≥L	18					15					9				
≥M	8					6					4				
S	1					<1					<1				

TABLE III. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS

10 - 15 MARCH 1965

b. ALASKA, CANADA AND GREENLAND

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
10-00 Z	86	80	6	0	0	93	7	0	0
-12	100	95	4	1	0	95	5	1	0
11-00	248	225	17	6	0	91	9	2	0
-12	171	146	12	13	0	85	15	8	0
12-00	184	142	25	14	3	77	23	9	2
-12	98	81	9	8	0	88	17	8	0
13-00	162	150	8	4	0	93	7	2	0
-12	66	59	5	1	1	89	11	3	2
14-00	130	114	11	5	0	88	12	4	0
-12	32	28	3	1	0	87	13	3	0
15-00	101	92	7	2	0	91	9	2	0
TOTAL	1378	1212	107	55	4	88	12	4	<1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
10-00 Z	5	5	0	0	0	38	34	4	0	0	43	41	2	0	0
-12	32	30	2	0	0	24	23	0	1	0	44	42	2	0	0
11-00	44	37	6	1	0	82	75	4	3	0	122	113	7	2	0
-12	28	25	1	2	0	64	48	9	7	0	79	73	2	4	0
12-00	22	17	4	1	0	67	43	14	10	0	95	82	7	3	3
-12	16	14	1	1	0	27	23	2	2	0	55	44	6	5	0
13-00	44	39	3	2	0	70	64	4	2	0	48	47	1	0	0
-12	11	10	1	0	0	28	23	3	1	1	27	26	1	0	0
14-00	27	22	5	0	0	42	33	5	4	0	61	59	1	1	0
-12	2	2	0	0	0	11	9	1	1	0	19	17	2	0	0
15-00	11	6	3	2	0	33	32	1	0	0	57	54	3	0	0
TOTAL	242	207	26	9	0	486	407	47	31	1	650	598	34	15	3
PERCENT NONE	86					84					92				
≥L	14					16					8				
≥M	4					7					3				
S	0					0					<1				

TABLE III. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS 10 - 15 MARCH 1965

c. CARIBBEAN

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
10-00 Z	2	2	0	0	0	100	0	0	0
-12	11	8	3	0	0	73	27	0	0
11-00	8	5	2	1	0	63	37	13	0
-12	4	2	2	0	0	50	50	0	0
12-00	9	9	0	0	0	100	0	0	0
-12	3	3	0	0	0	100	0	0	0
13-00	2	2	0	0	0	100	0	0	0
-12	2	2	0	0	0	100	0	0	0
14-00	13	11	1	1	0	85	15	8	0
-12	3	3	0	0	0	100	0	0	0
15-00	4	4	0	0	0	100	0	0	0
TOTAL	61	51	8	2	0	84	16	3	0

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
10-00 Z	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0
-12	2	1	1	0	0	4	4	0	0	0	5	3	2	0	0
11-00	2	1	0	1	0	5	4	1	0	0	1	0	1	0	0
-12	3	1	2	0	0	0	0	0	0	0	1	1	0	0	0
12-00	3	3	0	0	0	0	0	0	0	0	6	6	0	0	0
-12	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0
13-00	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0
-12	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0
14-00	4	2	1	1	0	8	8	0	0	0	1	1	0	0	0
-12	2	2	0	0	0	1	1	0	0	0	0	0	0	0	0
15-00	1	1	0	0	0	0	0	0	0	0	3	3	0	0	0
TOTAL	19	13	4	2	0	23	22	1	0	0	19	16	3	0	0
PERCENT NONE	68					96					84				
≥L	32					4					16				
≥M	11					0					0				
S	0					0					0				

TABLE III. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 10 - 15 MARCH 1965

d. MEXICO AND CENTRAL AMERICA

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY				PERCENT WITH			
		NONE	L	M	S	NONE	≥L	≥M	S
10-00 Z	2	2	0	0	0	100	0	0	0
-12	7	7	0	0	0	100	0	0	0
11-00	4	4	0	0	0	100	0	0	0
-12	4	3	1	0	0	75	25	0	0
12-00	13	12	1	0	0	92	8	0	0
-12	8	7	1	0	0	88	12	0	0
13-00	14	14	0	0	0	100	0	0	0
-12	10	10	0	0	0	100	0	0	0
14-00	9	9	0	0	0	100	0	0	0
-12	5	5	0	0	0	100	0	0	0
15-00	7	7	0	0	0	100	0	0	0
TOTAL	83	80	3	0	0	96	4	0	0

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	A NUMBER OCCURRENCES OF INTENSITY				B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	B NUMBER OCCURRENCES OF INTENSITY				C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	C NUMBER OCCURRENCES OF INTENSITY			
		NONE	L	M	S		NONE	L	M	S		NONE	L	M	S
10-00 Z	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0
-12	2	2	0	0	0	3	3	0	0	0	2	2	0	0	0
11-00	1	1	0	0	0	2	2	0	0	0	1	1	0	0	0
-12	0	0	0	0	0	3	2	1	0	0	1	1	0	0	0
12-00	3	2	1	0	0	3	3	0	0	0	7	7	0	0	0
-12	0	0	0	0	0	6	6	0	0	0	2	1	1	0	0
13-00	2	2	0	0	0	5	5	0	0	0	7	7	0	0	0
-12	2	2	0	0	0	7	7	0	0	0	1	1	0	0	0
14-00	1	1	0	0	0	2	2	0	0	0	6	6	0	0	0
-12	0	0	0	0	0	3	3	0	0	0	2	2	0	0	0
15-00	0	0	0	0	0	4	4	0	0	0	3	3	0	0	0
TOTAL	11	10	1	0	0	39	38	1	0	0	33	32	1	0	0
PERCENT NONE		91				97					97				
≥L		9				3					3				
≥M		0				0					0				
S		0				0					0				

TABLE IV. LOCATION OF SEVERE TURBULENCE OCCURRENCES 10 - 15 March 1965

TIME	SQUARE	LAYER	AREA
11-0000Z	141	B	N. Atlantic
11-0000	142	B	N. Atlantic
11-0000	147	B	N. Atlantic
12-0000	114	C	N. Atlantic
12-0000	129	C	Canada
12-0000	141	C	N. Atlantic
12-0000	130	C	Canada
12-0000	130	C	Canada
13-1200	138	B	N. Atlantic
13-1200	112	B	N. Atlantic
14-0000	141	C	N. Atlantic
14-1200	121	A	N. Atlantic

The sequence of upper level circulation patterns during the 5-day period is illustrated by the 0000Z 300-mb charts, shown in Figures 21-26. At the beginning of the period, 10-0000Z (Fig. 21), there were two major troughs extending southwest and southeast from a low center west of Greenland. The contour gradients associated with these troughs were not too strong. The greatest contour gradients were along a major jet stream well to the south across the Atlantic. The sharpest curvature of flow was just north of the Great Lakes around the trough. Another weak trough system was located off the southwestern United States coast.

Twenty-four hours later, as shown on the 11-0000Z chart (Fig. 22), the trough over eastern Canada moved into a more north-south alignment, with increasing curvature of flow and contour gradients off the east coast of the United States.

By 12-0000Z (Fig. 23), the lower end of the trough over the western Atlantic had moved eastward, causing increased contour gradients and sharply increased curvature in the flow patterns off Nova Scotia and Newfoundland.

The 300-mb chart for 13-0000Z (Fig. 24) indicated that the southern portion of this low pressure system had been displaced eastward and the high pressure ridge over the eastern Atlantic had intensified. This was associated with strong contour gradients and sharply curved flow patterns around the eastern portion of the low and the high pressure ridge. By 14-0000Z (Fig. 25), this low pressure system had been displaced about 5 degrees to the north with no further eastward movement.

At the end of the 5-day period, shown by the 15-0000Z chart (Fig. 26), a broad west-east low pressure system extended from 85°W to 25°W longitude. The contour gradients were weak north of 45°N latitude except east of 25°W longitude. Strong contour gradients were still present along the jet stream, but this jet stream, now oriented generally west to east over the Western Atlantic, was south of the main routes. In the eastern Atlantic, the jet curved northward to above 50°N near Ireland.

The positions of the jet streams and isotach patterns are shown at the 12-hour synoptic times, along with the total number of flights and the number of moderate or greater turbulence occurrences at each square in Figures 27-37. During the entire 5-day period, there was a major jet stream across the southern United States and between 30-40°N latitude across the Atlantic, with several other strong jet segments. This well developed jet stream was characterized by strong winds, as indicated by 150 and in some cases 175-knot isotachs. During the first two days, the major jet was located generally between 30 and 40°N over the Atlantic. By 12-1200Z, the portion of the jet over the eastern Atlantic became more anticyclonically curved and was displaced to the north, reaching to 50°N latitude by 13-0000Z. By 14-0000Z, there was a double jet structure, with the northern jet still located in the region of 50°N latitude. At the end of the period (15-0000Z), the double jet had consolidated into a single jet, with only the eastern portion of the jet curving northward to around 50°N latitude.

The occurrences of moderate or greater turbulence during this 5-day period appeared to be associated with several significant meteorological patterns. In the following discussion, the term turbulence will be confined to moderate or greater. During the first period, illustrated by the 10-0000Z charts (Figures 21 and 27), there were only a few scattered turbulence occurrences or 10 percent squares over the entire area. The regions of strong wind speed, horizontal wind shear, and contour gradients were at latitudes well to the south of the major international routes, and there were only a few flights in these regions.

The next chart, for 10-1200Z (Fig. 28), indicated a few scattered turbulence occurrences and 10 percent squares associated with the 150-knot isotach off the United States coast. An increasing number of turbulence occurrences and 10 percent squares were present during the next period, 11-0000Z (Figures 21 and 29). These were concentrated mostly in the trough off the southeastern United States and to the west and north of the 125-knot isotach along the jet stream in the central Atlantic. There were a few 10 percent squares along short jet segments in Canada.

On the 11-1200Z chart (Fig. 30), there appeared a change in the upper air pattern. Turbulence appeared in the region of increasing curvature of the flow around the low pressure trough off Nova Scotia. An inspection of the 12-0000Z charts (Figures 23 and 31) indicated an increase in the turbulence occurrences and 10 percent squares. These were mostly concentrated in the region of increasingly curved flow patterns between the low pressure trough which had been displaced eastward and the building high pressure ridge to the east. This was also a region of divergence between the southwest-northeast major jet and the northerly jet segment from Newfoundland to Iceland. Five occurrences of severe turbulence were reported in this region.

During the next period, illustrated by the 12-1200Z (Fig. 32), most of the turbulence occurrences were located in the Newfoundland-Nova Scotia area and to the north of the major jet. This portion of the jet was being displaced northward with increasing anticyclonic curvature. The charts for 13-0000Z (Figures 24 and 33) indicated a decided increase in the amount of turbulence. Some turbulence was associated with the 150-knot isotach off the Carolina-Virginia coast. However, most of the turbulence was associated with the increased contour gradient as the low was displaced eastward and the high pressure ridge intensified. The curvature of the flow patterns around these systems had increased. The eastward portion of the major jet had been displaced to almost 50°N latitude with increasing anticyclonic curvature.

On the next chart for 13-1200Z (Fig. 34), the region of turbulence was displaced eastward but was still associated with the same general meteorological pattern as on the previous chart. Two isolated occurrences of severe turbulence were reported. The amount of turbulence decreased during the next period, as indicated on the charts for 14-0000Z (Figures 25 and 35), but was still concentrated in the region of fairly sharply curved flow around the low pressure trough and high pressure ridge and in the divergence zone between the two jets. There were two reports of severe turbulence off Nova Scotia.

The amount of turbulence continued to decrease in the next period, as can be seen on the 14-1200Z chart (Fig. 36). A few scattered 10 percent squares were located in the eastern Atlantic as the troughs and ridges weakened.

The charts for 15-0000Z (Figures 26 and 37) indicated only a few scattered turbulence occurrences as the contour gradients, curvature of flow, and horizontal wind shear decreased north of 40°N latitude. Except in the extreme eastern Atlantic, the major jet was oriented largely west to east. Strong wind speeds and large horizontal wind shears were present along this jet, they were located well to the south of the international air routes, and they were almost no flights were made in this region.

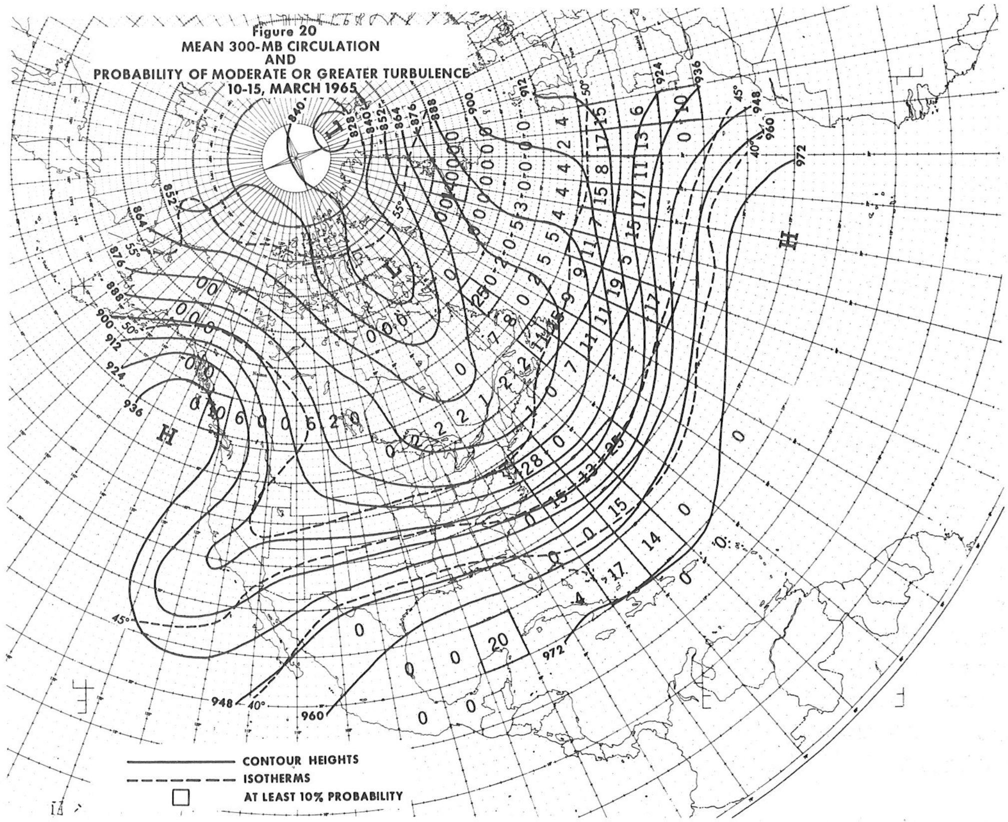

Figure 20
MEAN 300-MB CIRCULATION
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
10-15, MARCH 1965

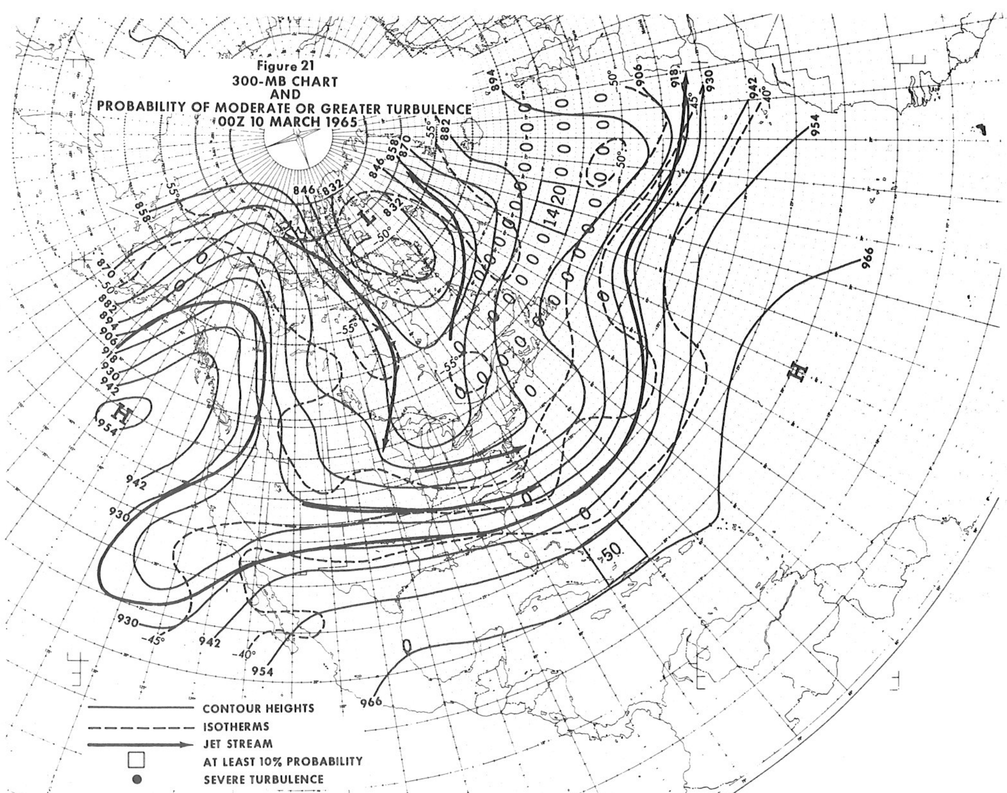

Figure 21
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 10 MARCH 1965

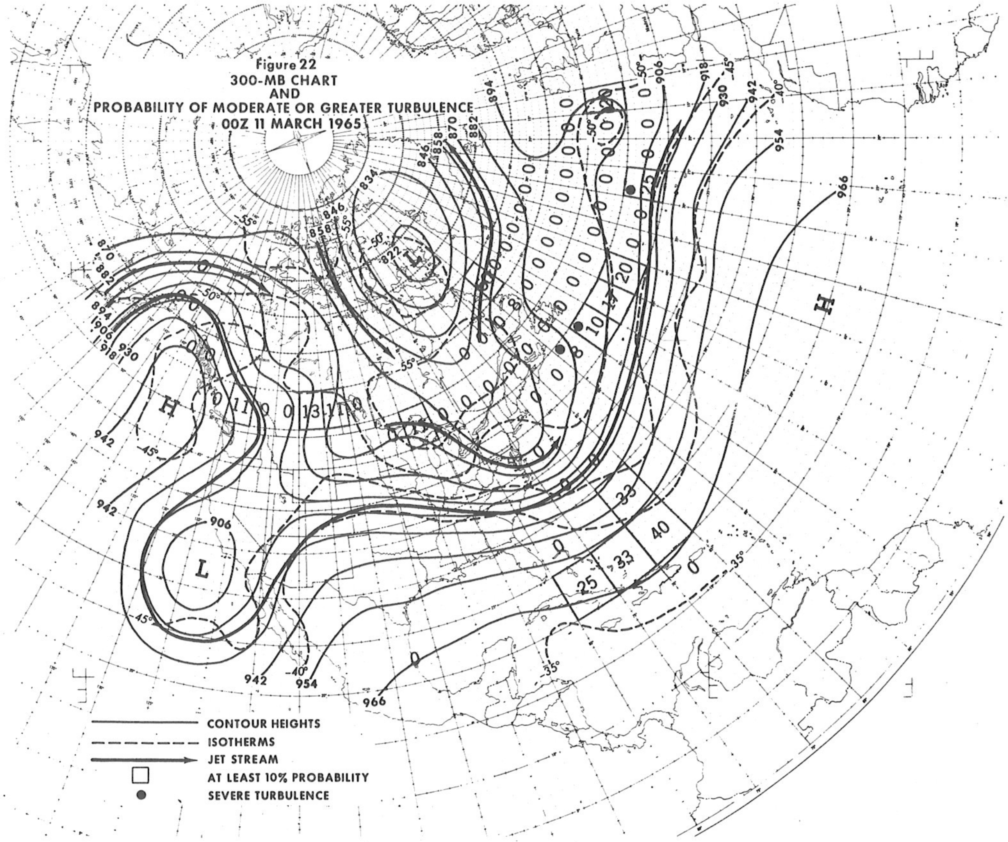
Figure 22
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 11 MARCH 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

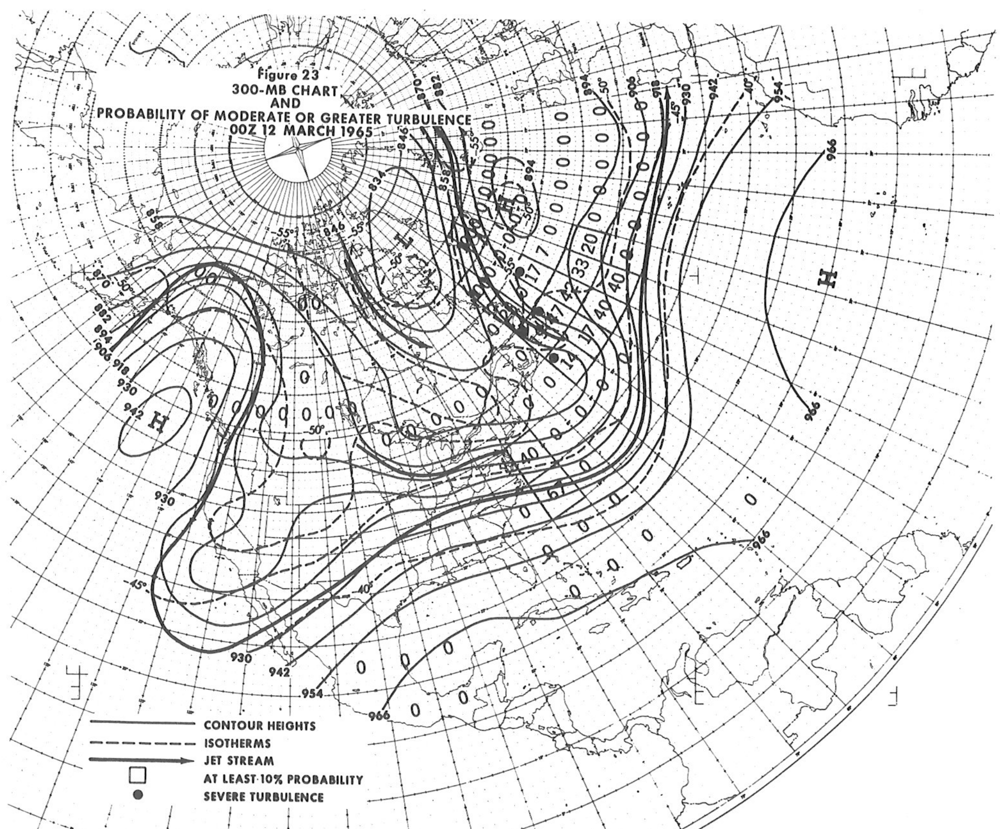
Figure 23
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 12 MARCH 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

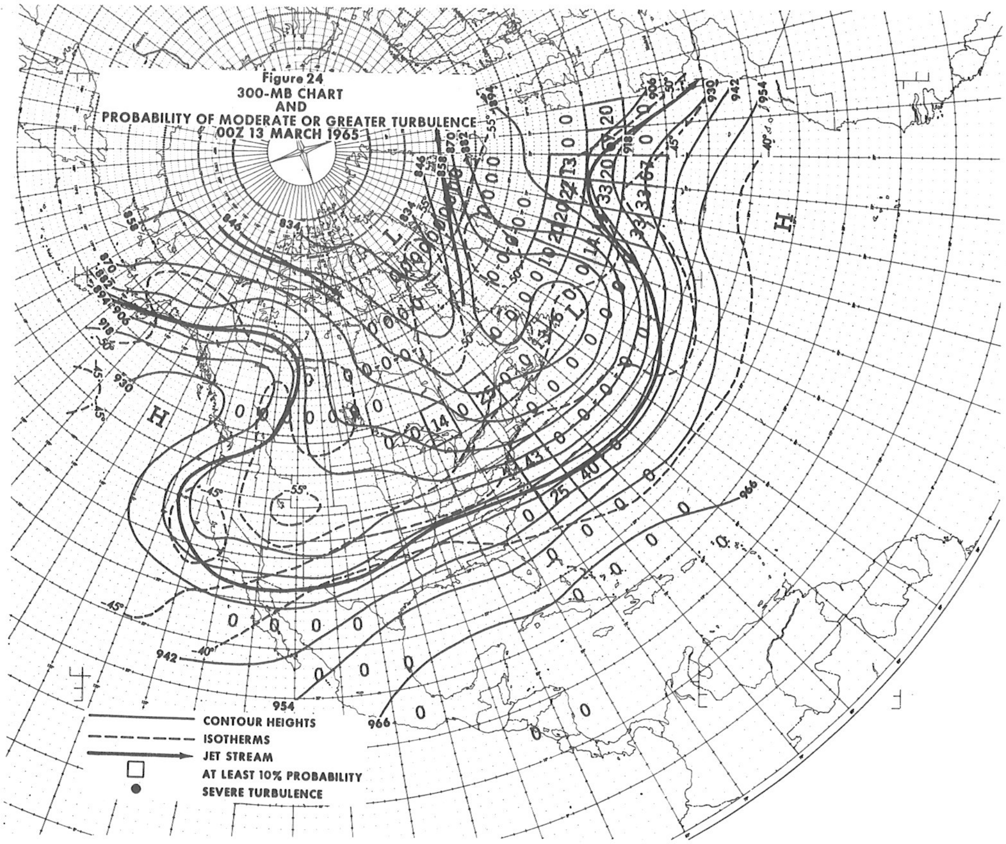
Figure 24
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 13 MARCH 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

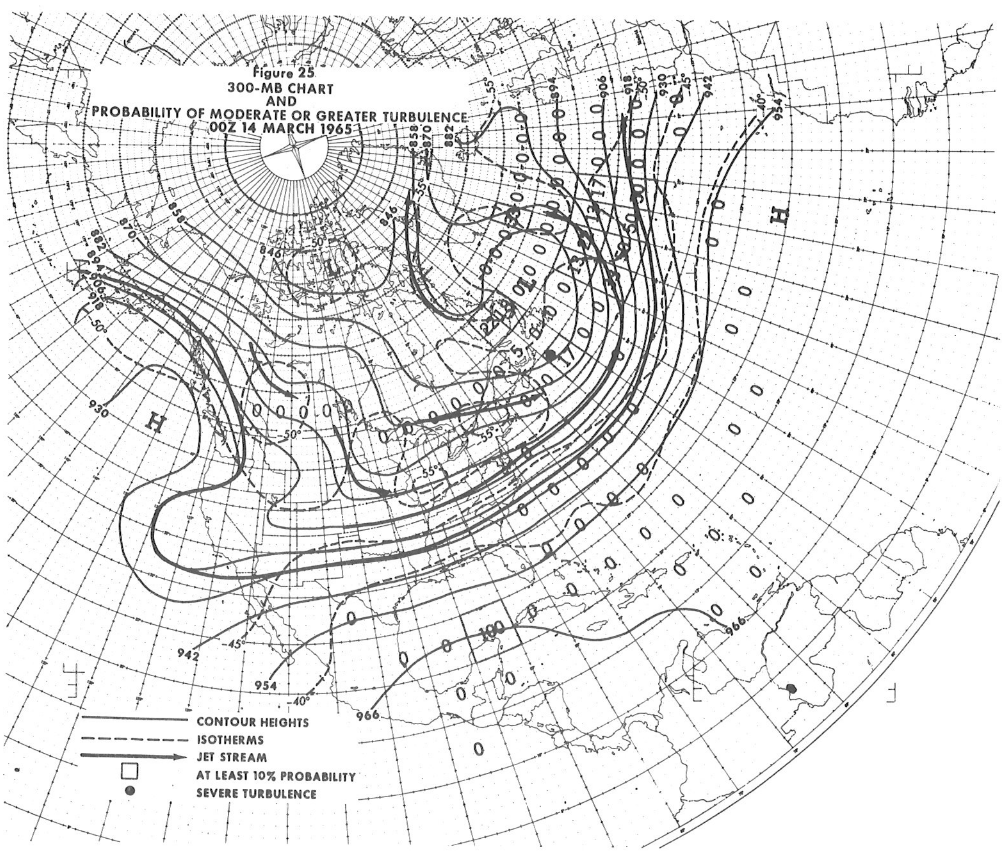
Figure 25
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 14 MARCH 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

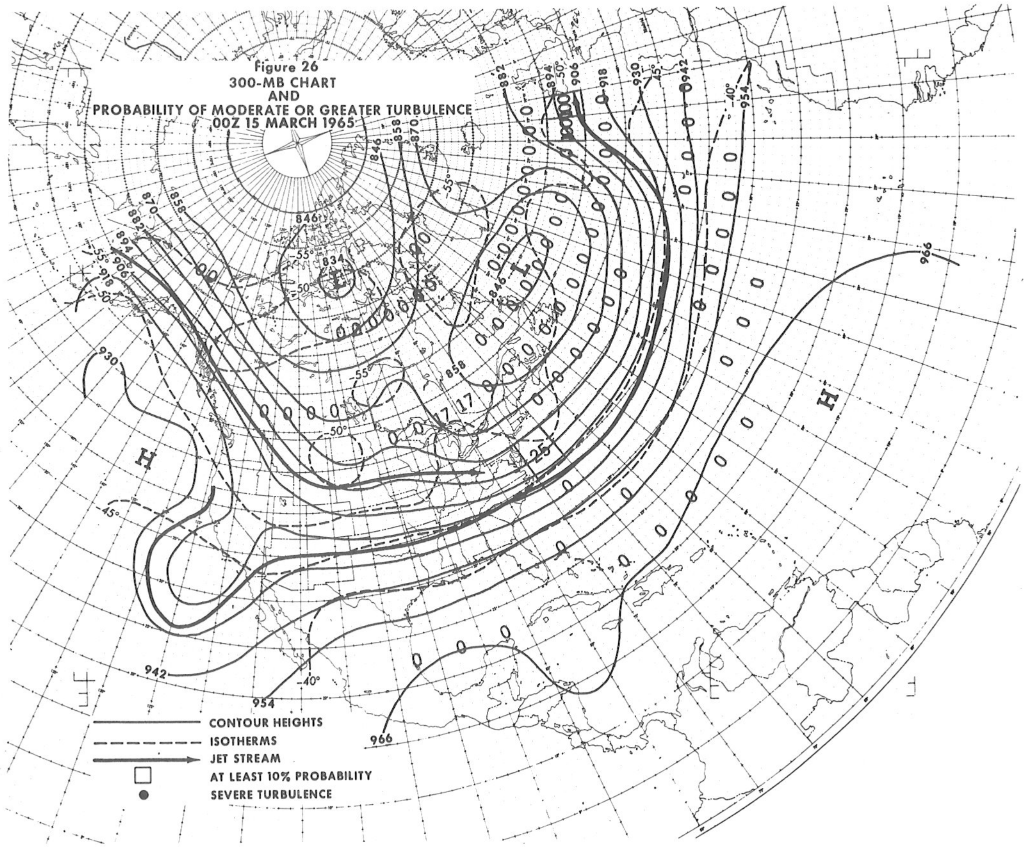
Figure 26
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 15 MARCH 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

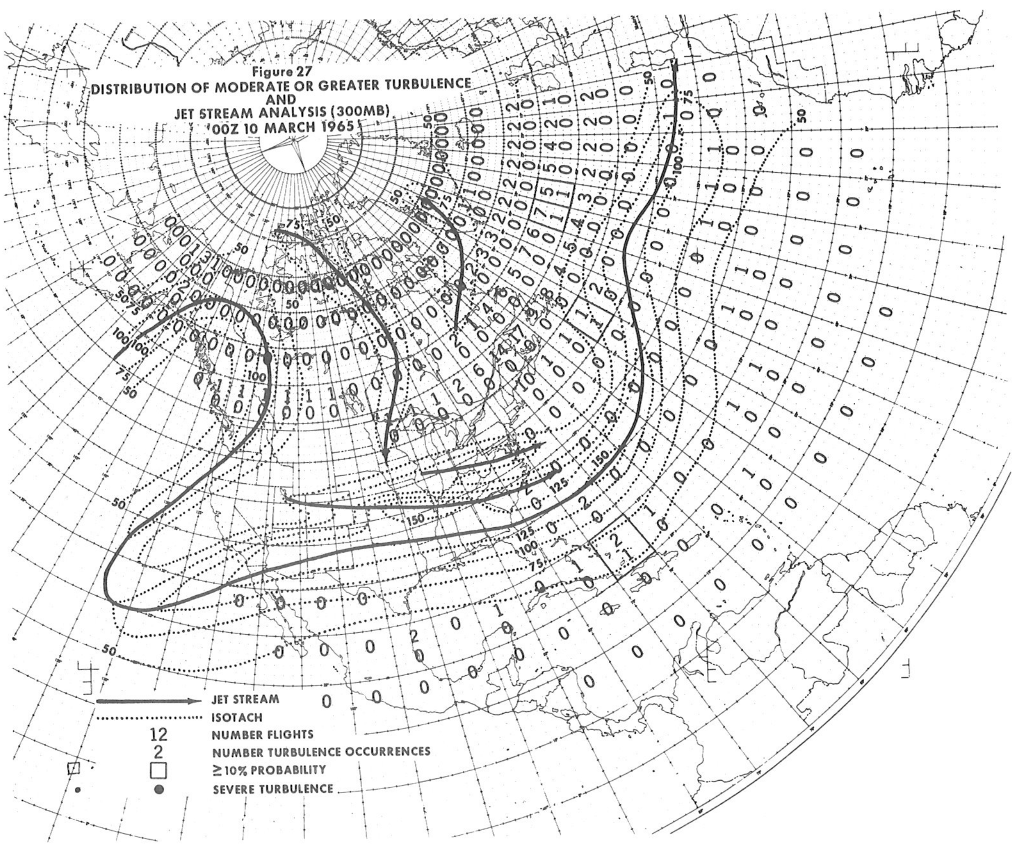
Figure 27
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 10 MARCH 1965
JET STREAM
ISOTACH
12
NUMBER FLIGHTS
2
NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

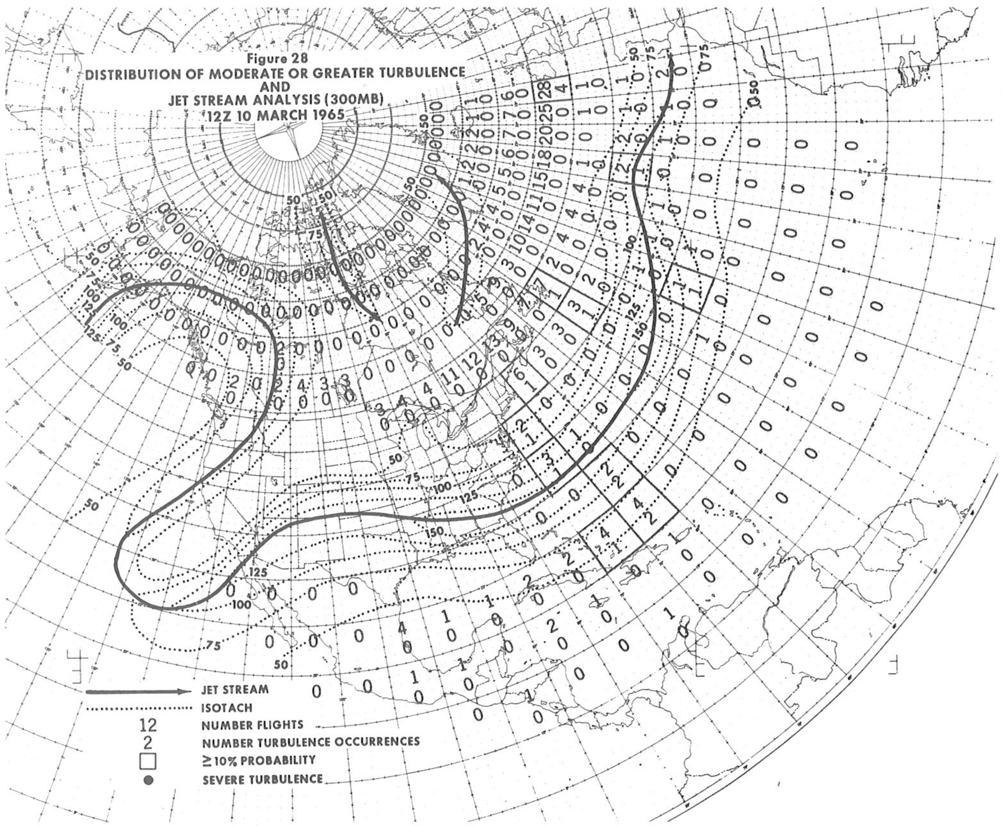
Figure 28
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 10 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

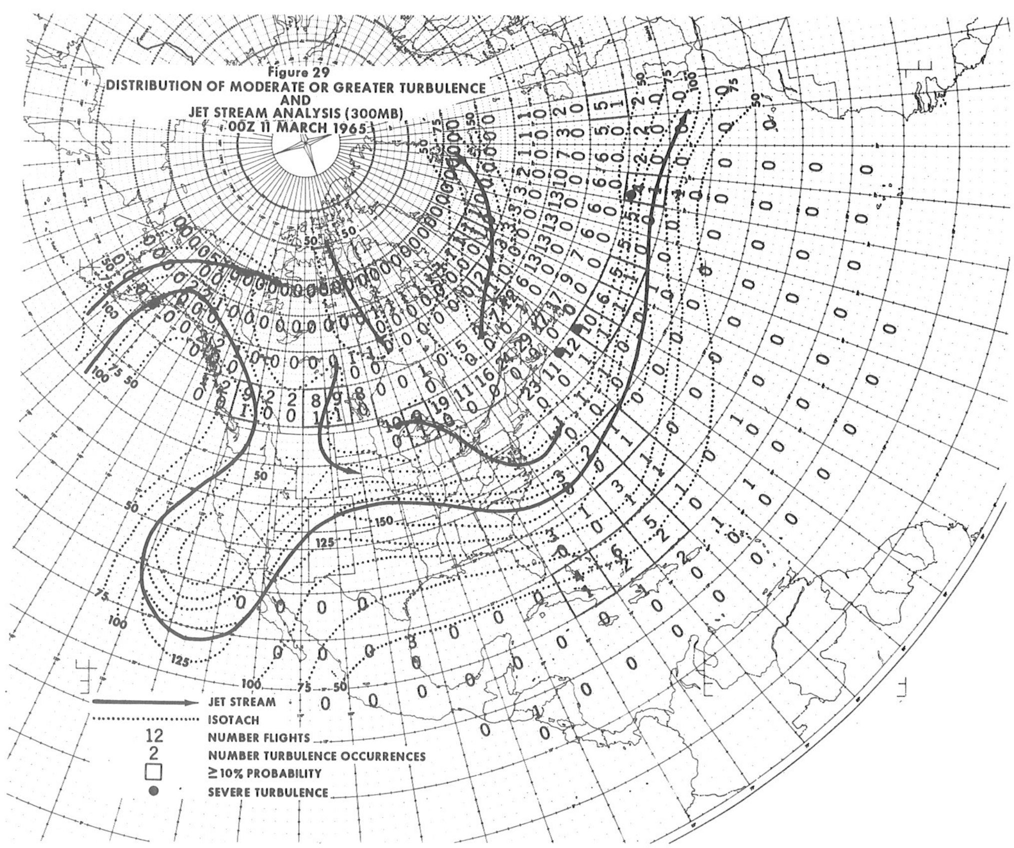
Figure 29
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 11 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

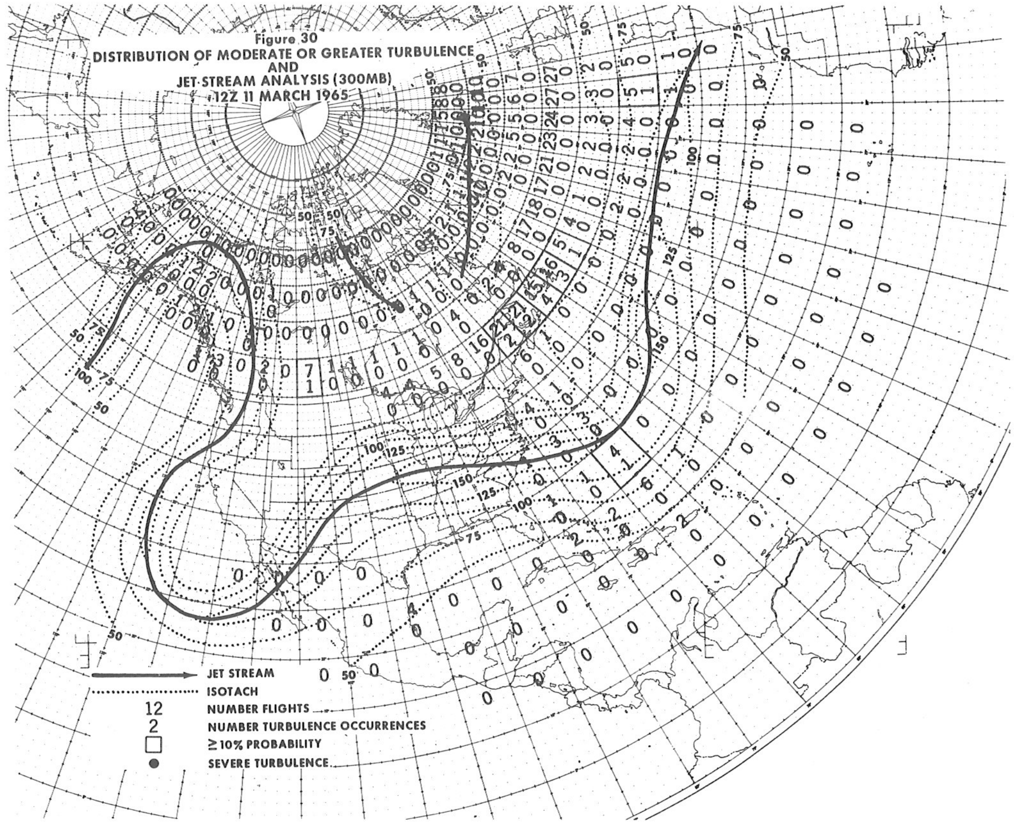
Figure 30
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 11 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

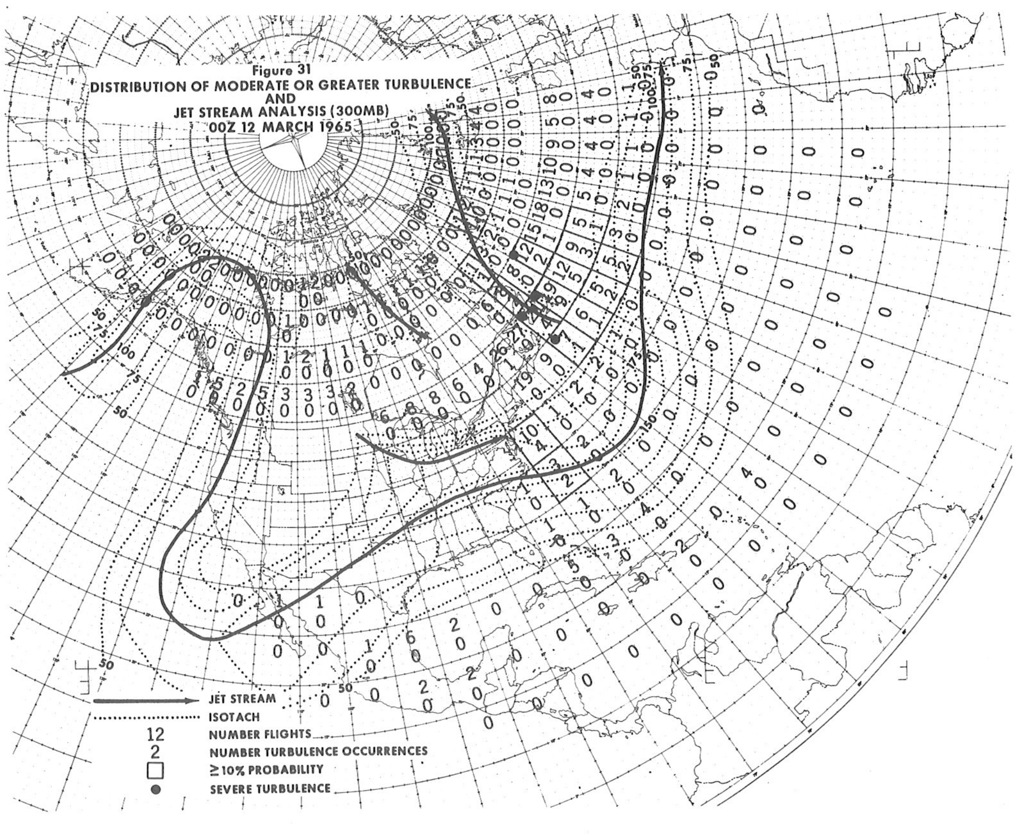
Figure 31
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 12 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

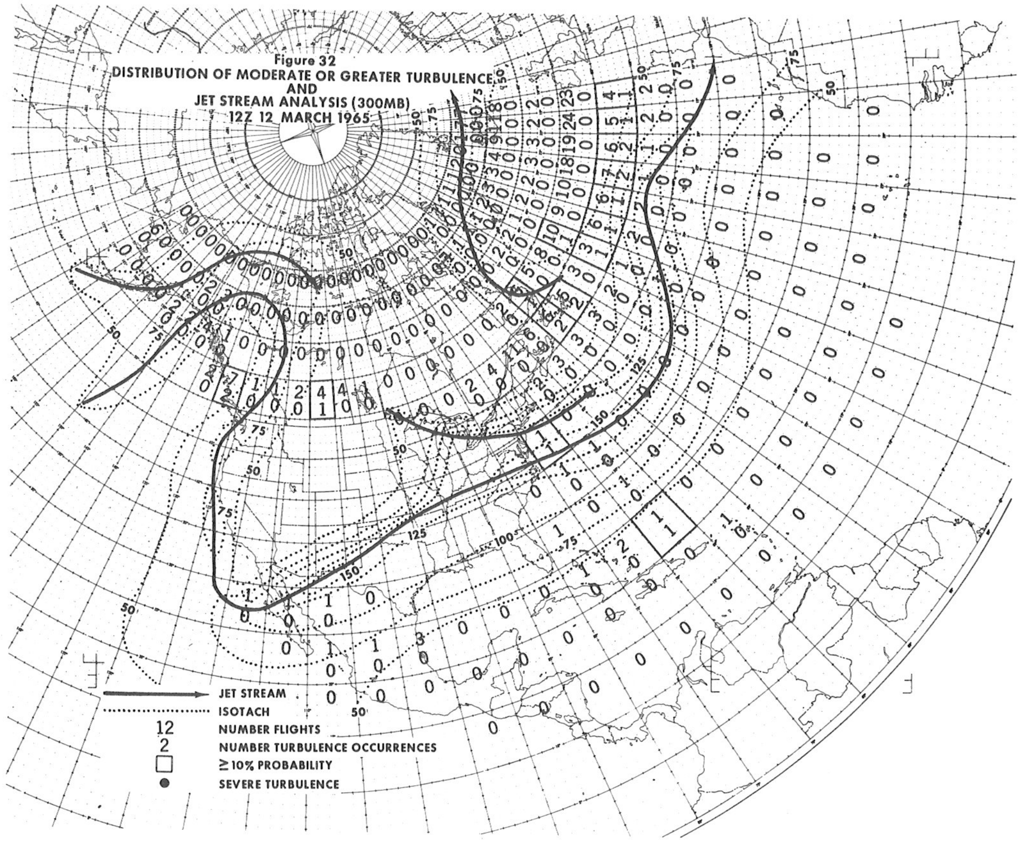
Figure 32
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 12 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

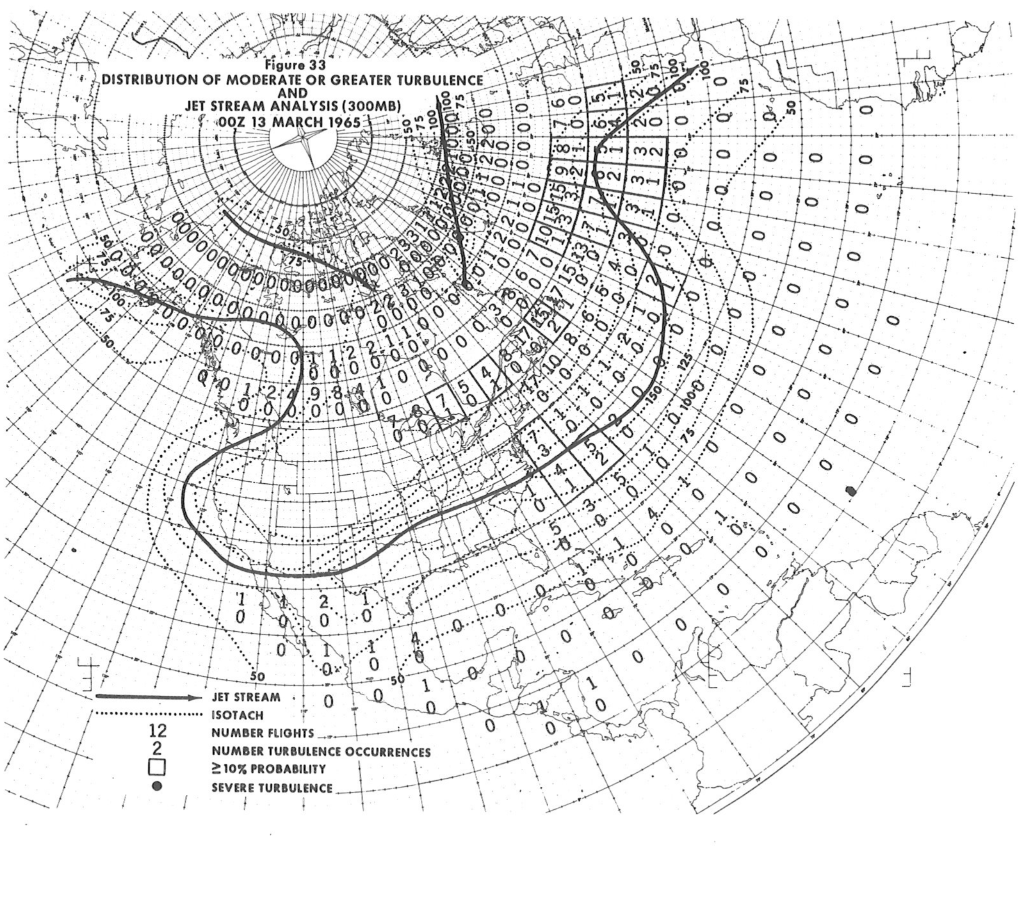
Figure 33
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 13 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

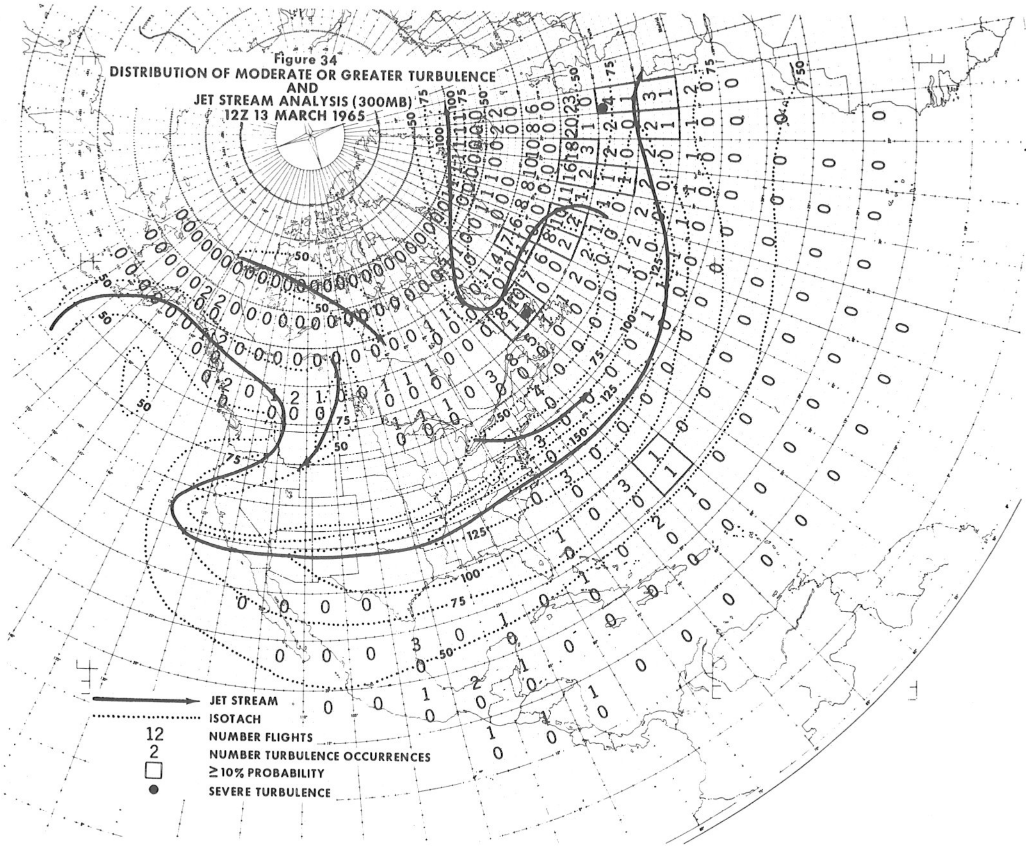
Figure 34
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 13 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

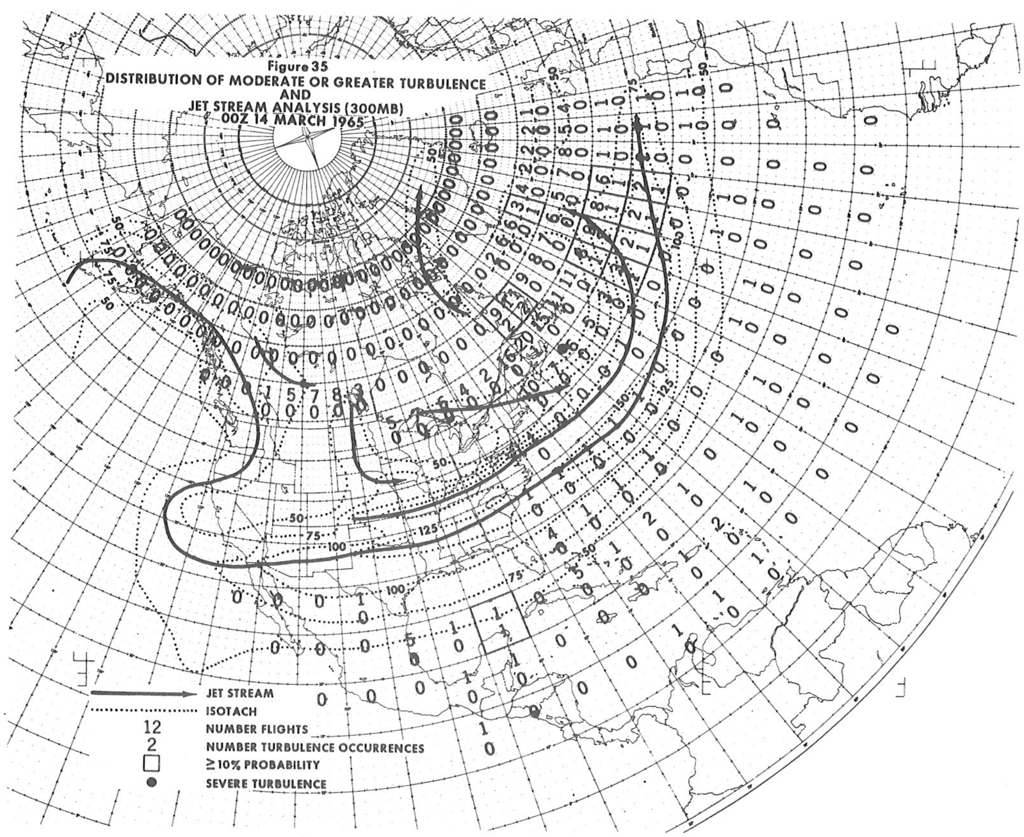
Figure 35
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 14 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

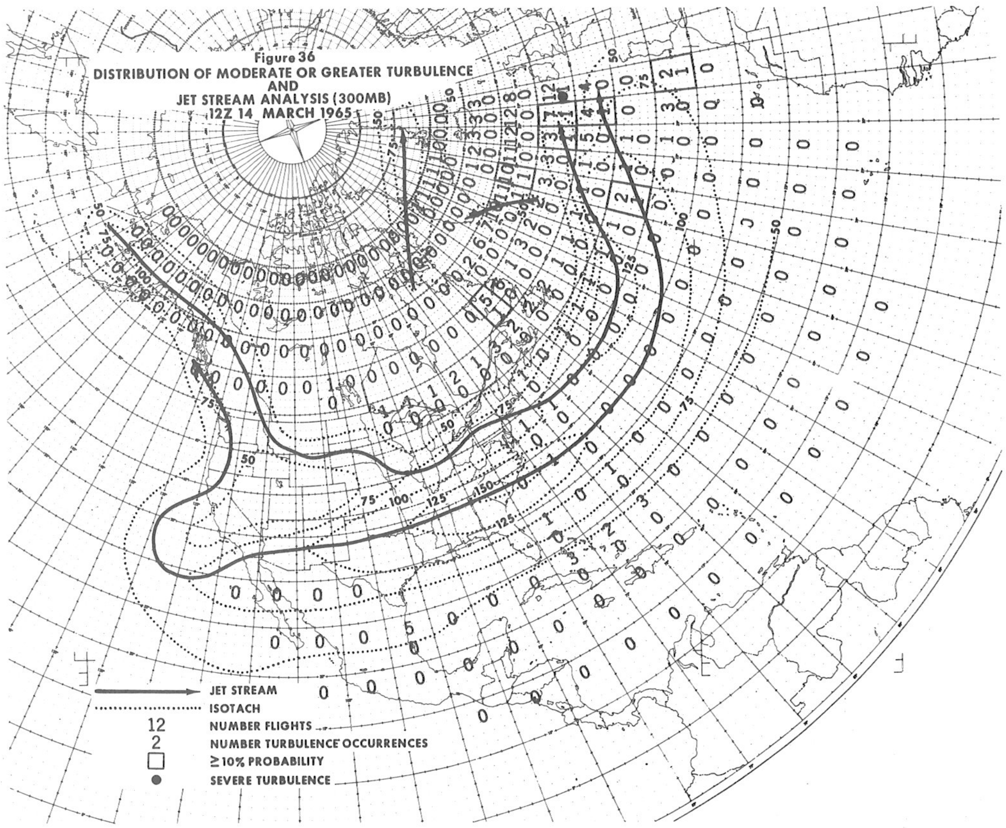

Figure 36
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 14 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

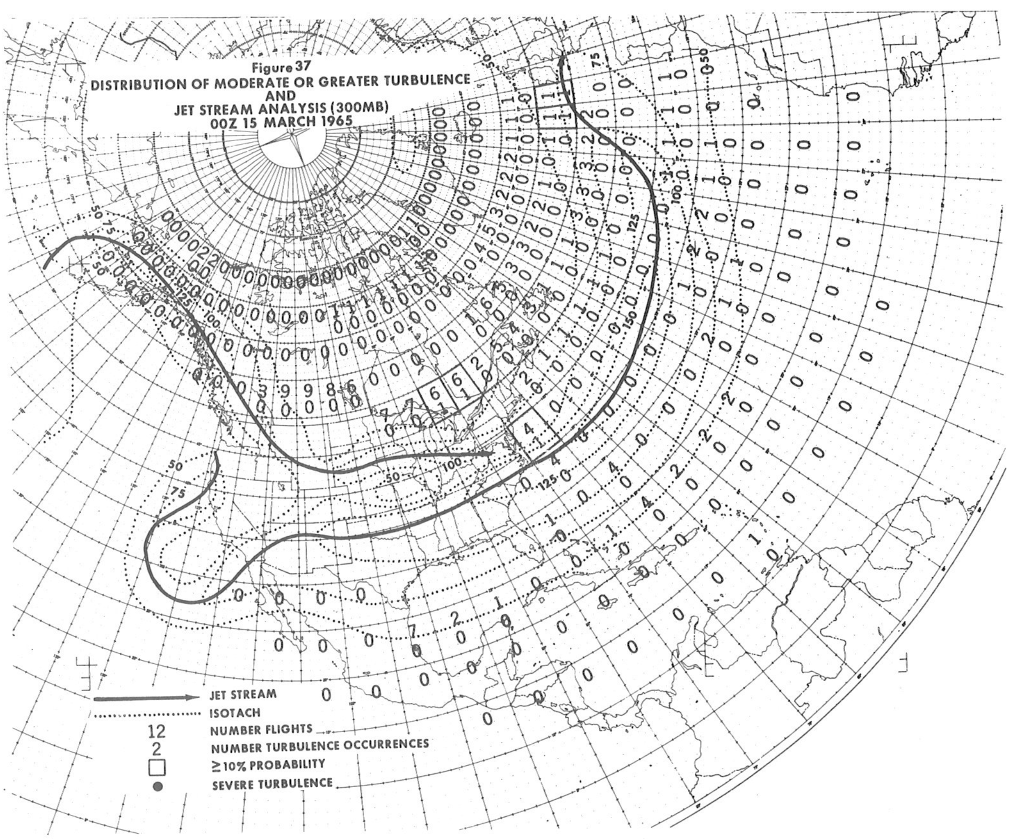

Figure 37
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 15 MARCH 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

IV. 9 - 14 JUNE 1965 DATA COLLECTION PERIOD

A. SUMMARY OF JUNE DATA

A tabulation of the turbulence data for each 12-hour period is shown in Table V for 9 - 14 June 1965. The overall frequency of moderate or greater turbulence for the entire 5-day period was 3 percent over the North Atlantic, 5 percent over ACG, 7 percent over the Caribbean, and 0 percent over Mexico and Central America. The frequency of various intensities of turbulence varied considerably in individual 12-hour periods. The frequency of moderate or greater turbulence varied from 1 to 10 percent over the North Atlantic and from 1 to 15 percent over ACG. As in the other data periods, the total number of flights over the Caribbean, Mexico, and Central America was quite small, and the percentages are not as significant as over the other two areas.

The frequency of no turbulence increased and the frequency of both light or greater and moderate or greater decreased with altitude over both the North Atlantic and ACG. Since the number of flights over the other areas was quite small, it was difficult to attach much significance to the variation with altitude layers.

Only four occurrences of severe turbulence were reported during the entire 5-day period, as shown in Table VI; with one report in layer A, two reports in layer B, and 1 report in layer C. These four occurrences were scattered during three of the last four 12-hour time periods.

Only 42 squares had a total of at least 40 flight squares during the entire 5-day period.

B. METEOROLOGICAL ANALYSIS

The mean 300-mb chart for the 9-14 June 1965 data collection period is shown in Figure 38. Most of the moderate or greater turbulence and the 10 percent squares were confined to the cut-off low southeast of Florida and to the stronger contour gradients around the closed low pressure center over the Central Atlantic. Three 10 percent squares were associated with fairly strong winds over the Coastal and Rocky mountains of Western Canada and with the trough extending from Alaska into the western United States.

TABLE VI. LOCATION OF SEVERE TURBULENCE OCCURRENCES 9 - 14 June 1965

DATE-TIME	SQUARE	LAYER	LOCATION
12-1200Z	99	A	Canada
13-0000Z	128	B	Canada
13-0000Z	140	C	North Atlantic
14-0000Z	130	B	Canada

TABLE V. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 9 - 14 JUNE 1965

a. NORTH ATLANTIC

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY				PERCENT WITH			
		NONE	L	M	S	NONE	≥L	≥M	S
09-00 Z	150	116	24	10	0	77	23	7	0
-12	248	235	9	4	0	95	5	2	0
10-00	309	280	22	7	0	91	9	2	0
-12	390	364	24	2	0	93	7	1	0
11-00	326	309	15	2	0	95	5	1	0
-12	279	248	22	9	0	89	11	3	0
12-00	324	302	15	7	0	93	7	2	0
-12	355	321	22	12	0	90	10	3	0
13-00	384	341	33	9	1	89	11	3	<1
. 12	296	260	25	11	0	88	12	4	0
14-00	218	179	17	22	0	82	18	10	0
TOTAL	3279	2955	228	95	1	90	10	3	<1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	A NUMBER OCCURRENCES OF INTENSITY				B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	B NUMBER OCCURRENCES OF INTENSITY				C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	C NUMBER OCCURRENCES OF INTENSITY			
		NONE	L	M	S		NONE	L	M	S		NONE	L	M	S
09-00 Z	7	5	0	2	0	91	68	15	8	0	52	43	9	0	0
-12	14	14	0	0	0	80	73	5	2	0	154	148	4	2	0
10-00	19	15	4	0	0	151	132	13	6	0	139	133	5	1	0
-12	18	16	0	2	0	142	125	17	0	0	230	223	7	0	0
11-00	13	13	0	0	0	135	129	4	2	0	178	167	11	0	0
-12	16	15	0	1	0	126	103	15	8	0	137	130	7	0	0
12-00	33	29	4	0	0	195	181	9	5	0	96	92	2	2	0
-12	3	2	1	0	0	150	128	15	7	0	202	191	6	5	0
13-00	37	32	3	2	0	180	156	20	4	0	167	153	10	3	1
-12	8	4	0	4	0	176	153	19	4	0	112	103	6	3	0
14-00	19	8	2	9	0	104	84	9	11	0	95	87	6	2	0
TOTAL	187	153	14	20	0	1530	1332	141	57	0	1562	1470	73	18	1
PERCENT NONE	82					87					94				
≥L	18					13					6				
M	11					4					1				
S	0					0					<1				

TABLE V. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS 9 - 14 JUNE 1965

b. ALASKA, CANADA AND GREENLAND

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
09-00 Z	72	55	16	1	0	76	24	1	0
-12	157	138	10	9	0	88	12	6	0
10-00	264	226	24	14	0	86	14	5	0
-12	144	125	15	4	0	87	13	3	0
11-00	250	205	32	13	0	82	18	5	0
-12	114	97	9	8	0	85	15	7	0
12-00	248	208	32	8	0	84	16	3	0
-12	152	126	18	7	1	83	17	5	1
13-00	170	144	21	4	1	85	15	3	1
-12	98	75	19	4	0	77	23	4	0
14-00	141	102	18	20	1	72	28	15	1
TOTAL	1810	1501	214	92	3	83	17	5	<1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
09-00 Z	9	8	1	0	0	31	23	8	0	0	32	24	7	1	0
-12	29	25	2	2	0	31	29	0	2	0	97	84	8	5	0
10-00	40	31	3	6	0	94	76	15	3	0	130	119	6	5	0
-12	18	15	1	2	0	34	22	10	2	0	92	88	4	0	0
11-00	22	18	3	1	0	89	67	14	8	0	139	120	15	4	0
-12	10	7	2	1	0	40	32	3	5	0	64	58	4	2	0
12-00	16	9	7	0	0	131	108	17	6	0	101	91	8	2	0
-12	2	1	0	0	1	43	31	7	5	0	107	94	11	2	0
13-00	9	8	1	0	0	88	74	9	4	1	73	62	11	0	0
-12	20	12	7	1	0	25	20	4	1	0	53	43	8	2	0
14-00	17	10	5	2	0	54	36	5	12	1	70	56	8	6	0
TOTAL	192	144	32	15	1	660	518	92	48	2	958	839	90	29	0
PERCENT NONE	75					78					88				
≥L	25					22					12				
≥M	8					8					3				
S	1					<1					0				

TABLE V. DISTRIBUTION OF TURBULENCY BY 12-HOUR PERIODS — 9 - 14 JUNE 1965

c. CARIBBEAN

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S	PERCENT WITH: NONE	≥L	≥M	S
09-00 Z	2	2	0	0	0	100	0	0	0
-12	8	6	0	2	0	75	25	25	0
10-00	8	6	2	0	0	75	25	0	0
-12	6	6	0	0	0	100	0	0	0
11-00	12	10	2	0	0	83	17	0	0
-12	14	9	2	3	0	64	36	21	0
12-00	7	6	1	0	0	86	14	0	0
-12	17	12	5	0	0	71	29	0	0
13-00	7	7	0	0	0	100	0	0	0
-12	7	5	1	1	0	71	29	14	0
14-00	2	2	0	0	0	100	0	0	0
TOTAL	90	71	13	6	0	79	21	7	0

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	A: NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	B: NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	C: NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S
09-00 Z	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
-12	0	0	0	0	0	8	6	0	2	0	0	0	0	0	0
10-00	1	0	1	0	0	5	4	1	0	0	2	2	0	0	0
-12	4	4	0	0	0	2	2	0	0	0	0	0	0	0	0
11-00	3	3	0	0	0	9	7	2	0	0	0	0	0	0	0
-12	5	5	0	0	0	9	4	2	3	0	0	0	0	0	0
12-00	0	0	0	0	0	7	6	1	0	0	0	0	0	0	0
-12	4	3	1	0	0	7	4	3	0	0	6	5	1	0	0
13-00	3	3	0	0	0	2	2	0	0	0	2	2	0	0	0
-12	2	1	0	1	0	2	2	0	0	0	3	2	1	0	0
14-00	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0
TOTAL	22	19	2	1	0	53	39	9	5	0	15	13	2	0	0
PERCENT NONE	86					74					87				
≥L	14					26					13				
≥M	5					9					0				
S	0					0					0				

TABLE V. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 9 - 14 JUNE 1965

d. MEXICO AND CENTRAL AMERICA

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
09-00 Z	4	4	0	0	0	100	0	0	0
-12	11	11	0	0	0	100	0	0	0
10-00	7	7	0	0	0	100	0	0	0
-12	2	2	0	0	0	100	0	0	0
11-00	5	5	0	0	0	100	0	0	0
-12	5	5	0	0	0	100	0	0	0
12-00	6	6	0	0	0	100	0	0	0
-12	4	4	0	0	0	100	0	0	0
13-00	5	5	0	0	0	100	0	0	0
-12	3	3	0	0	0	100	0	0	0
14-00	2	2	0	0	0	100	0	0	0
TOTAL	54	54	0	0	0	100	0	0	0

FURTHER DISTRIBUTION BY LAYERS

	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
09-00 Z	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0
-12	1	1	0	0	0	4	4	0	0	0	6	6	0	0	0
10-00	0	0	0	0	0	1	1	0	0	0	6	6	0	0	0
-12	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0
11-00	0	0	0	0	0	1	1	0	0	0	4	4	0	0	0
-12	1	1	0	0	0	1	1	0	0	0	3	3	0	0	0
12-00	0	0	0	0	0	1	1	0	0	0	5	5	0	0	0
-12	2	2	0	0	0	0	0	0	0	0	2	2	0	0	0
13-00	0	0	0	0	0	1	1	0	0	0	4	4	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0
14-00	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
TOTAL	4	4	0	0	0	10	10	0	0	0	40	40	0	0	0
PERCENT NONE	100					100					100				
≥L	0					0					0				
≥M	0					0					0				
S	0					0					0				

The sequence of upper air circulation patterns during this 5-day period is illustrated by the 0000Z 300-mb charts (Figures 39-44). At the start of the period, as shown by the 9-0000Z (Fig. 39), the area north of 40°N latitude was largely characterized by a series of low pressure troughs and centers. The most pronounced center was located northwest of the Great Lakes. The strongest contour gradients were confined to a narrow zone along the jet stream just south of the low pressure systems. Outside of a cut-off low in southwestern United States, the area south of 40°N latitude was characterized by weak contour gradients.

The low pressure centers near the Great Lakes and over the central Atlantic moved about 5 degrees eastward during the next 24 hours, as shown on the 10-0000Z 300-mb chart (Fig. 40), with some deepening of the Atlantic low. The ridge between the Alaska and Great Lakes troughs weakened, with the flow becoming more nearly zonal in this region. Weak contour gradients persisted south of 40°N latitude.

The 12-0000Z 300-mb chart (Fig. 41) indicated a 10 degree eastward displacement of the Canadian low but only a 5 degree eastward displacement of the Atlantic low. The ridge between these troughs intensified, with increasing curvature of the flow patterns around these systems. Again, the contour gradients were very weak south of 40°N latitude.

By 12-0000Z (Fig. 42), the Canadian low had moved eastward and had almost combined with the Atlantic low. The jet stream system and stronger contour gradients had been displaced somewhat southward over the Atlantic. The main change in the circulation was the intensification of the ridge over western Canada with more sharply curved flow patterns. On the 13-0000Z 300-mb chart (Fig. 43) the large flat low pressure system persisted over the Atlantic. The ridge over western Canada continued to intensify as the Alaskan low moved eastward. The low over southwest United States had nearly disappeared. These trends continued, as can be seen on the 14-0000Z 300-mb chart (Fig. 44). The lows in southeastern Canadian and the Atlantic were oriented in a more nearly west-east line. The curvature of the flow increased around the eastern end of this low pressure system. The high pressure ridge over central Canada intensified, with increasingly curved flow patterns and stronger contour gradients between the high and the western segment of the low pressure system. A weak trough was present southwest of Florida.

The locations of jet streams and isotach patterns at the 300-mb level are shown for each 12-hour map time in Figures 45-55. The total number of flights and the number of moderate or greater turbulence occurrences in each 12-hour interval centered at the 0000 and 1200 synoptic times are indicated at each square.

Only a few reports of turbulence were evident on the 9-0000Z 300-mb chart (Figures 39 and 45). These were scattered to the north of the double jet stream across the Atlantic and in the curved flow around the eastern portion of the trough. During the period centered at 9-1200Z (Fig. 46), there were only a few reports of turbulence. Some were associated with the curved flow around the western low and with the 100-knot isotach near the Great Lakes. Almost no flights were reported in the region of the 100-knot isotach and strong wind shear along the major jet across the Atlantic.

As indicated on the charts for 10-0000Z (Figures 40 and 47), the greatest concentration of turbulence and 10 percent squares were located in southwest Canada. The flow had become fairly strong from the southwest across the Coastal and Rocky Mountains and may have been associated with mountain wave activity. The other reports were well scattered, with a few along the jet and stronger contour gradients around the low pressure system over the central Atlantic. On the 10-1200Z 300-mb chart (Fig. 48), there were only a few scattered reports of turbulence.

Most of the turbulence during the 12-hour period centered at 11-0000Z (Figures 41 and 49) was widely scattered. The greatest concentration was in a convergence zone between the two jet segments northwest of the Great Lakes and in the area between the western low and the high pressure ridge off Newfoundland. The 11-1200Z 300-mb chart (Fig. 50) showed some turbulence concentrated in the increasingly curved flow around the two low centers and the intermediate high pressure ridge.

The 12-hour period centered at 12-0000Z (Figures 42 and 51) indicated widely scattered turbulence and 10 percent squares. Most of the turbulence was in the region of weakening anticyclonically curved flow between the two low centers. The 300-mb chart for 12-1200Z (Fig. 52) showed quite scattered turbulence. Most of the turbulence occurred around the cyclonically curved flow off Newfoundland. The three reports in southwest Canada, including one report of severe turbulence, were difficult to explain.

Little turbulence was reported during the 12-hour period centered at 13-0000Z (Figures 43 and 53). Most of this turbulence was near the entrance and exit zones of the 100-knot isotachs along the jet across the Atlantic. Two reports of severe turbulence were reported near Nova Scotia near a weak convergence zone.

Turbulence increased somewhat during the next period, as indicated on the 13-1200Z 300-mb chart (Fig. 54) but was still widely scattered. The increasing cyclonic curvature over New England indicated an intensification of the western portion of the low pressure system. Most of the turbulence was located in this developing trough and in the slightly anticyclonically curved flow between this trough and the other trough over the central Atlantic. Some turbulence could possibly be associated with the 100-knot isotach.

The last 12-hour period centered at 14-0000Z (Figures 44 and 55) showed an increase in the number of turbulence occurrences and 10 percent squares. One area of concentration appeared near the Great Lakes in the curved flow and strong horizontal wind shear and contour gradient between the low pressure system and the intensifying high pressure ridge. Another area of concentration was in the Nova Scotia-Newfoundland area in the anticyclonically curved flow between the two low pressure centers. This was also a region of strong horizontal wind shear between the two 100-knot isotachs. Another area of concentration was in the strongly curved flow around the eastern end of the low pressure system and the 100-knot isotachs. Another area of concentration was in the strongly curved flow around the eastern end of the low pressure system and the 100-knot isotachs. One occurrence of severe turbulence was reported in this region. A few scattered reports of turbulence were located in the elongated and nearly cut-off low off southeast United States.

During the entire 5-day period, the number of moderate or greater turbulence occurrences and 10 percent squares was somewhat lower than in the December and March data collection periods. In general, the wind speed, horizontal wind shear, and contour gradients were weaker during this June period. It was not possible to obtain very definite correlations between turbulence and meteorological patterns. Also, the zones of the strongest gradients and wind speeds were somewhat south of the major air routes, and the number of flights did not permit adequate testing in these zones.

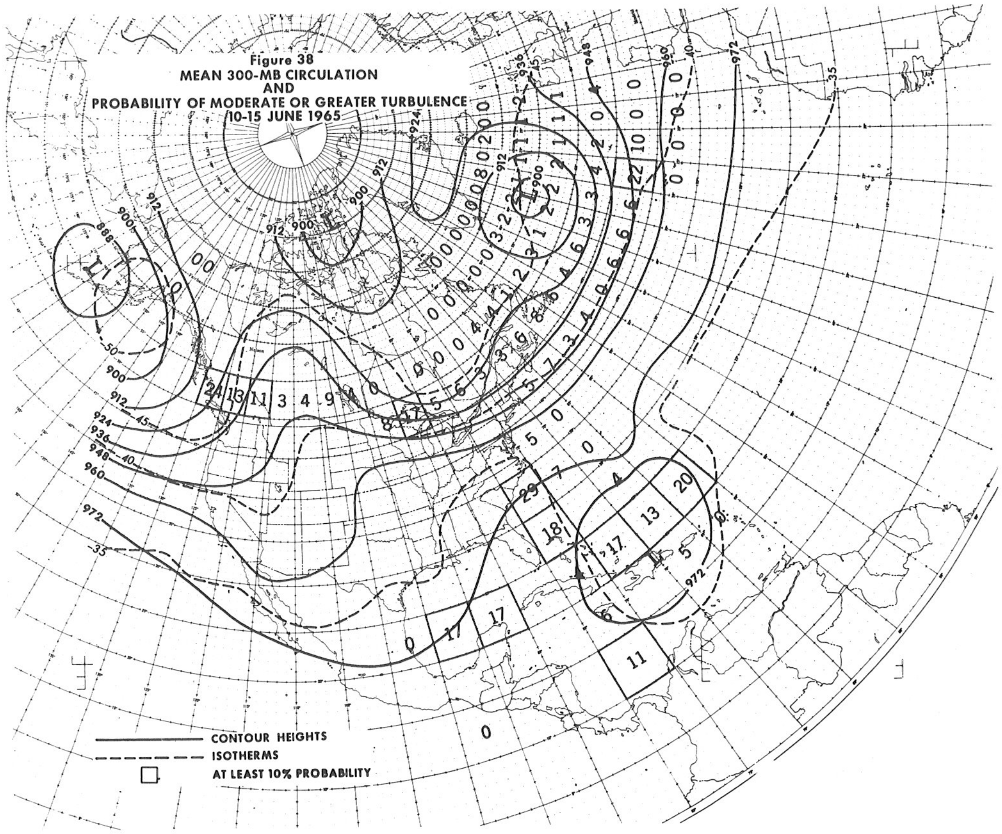
Figure 38
MEAN 300-MB CIRCULATION
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
10-15 JUNE 1965
CONTOUR HEIGHTS
ISOTHERMS
AT LEAST 10% PROBABILITY

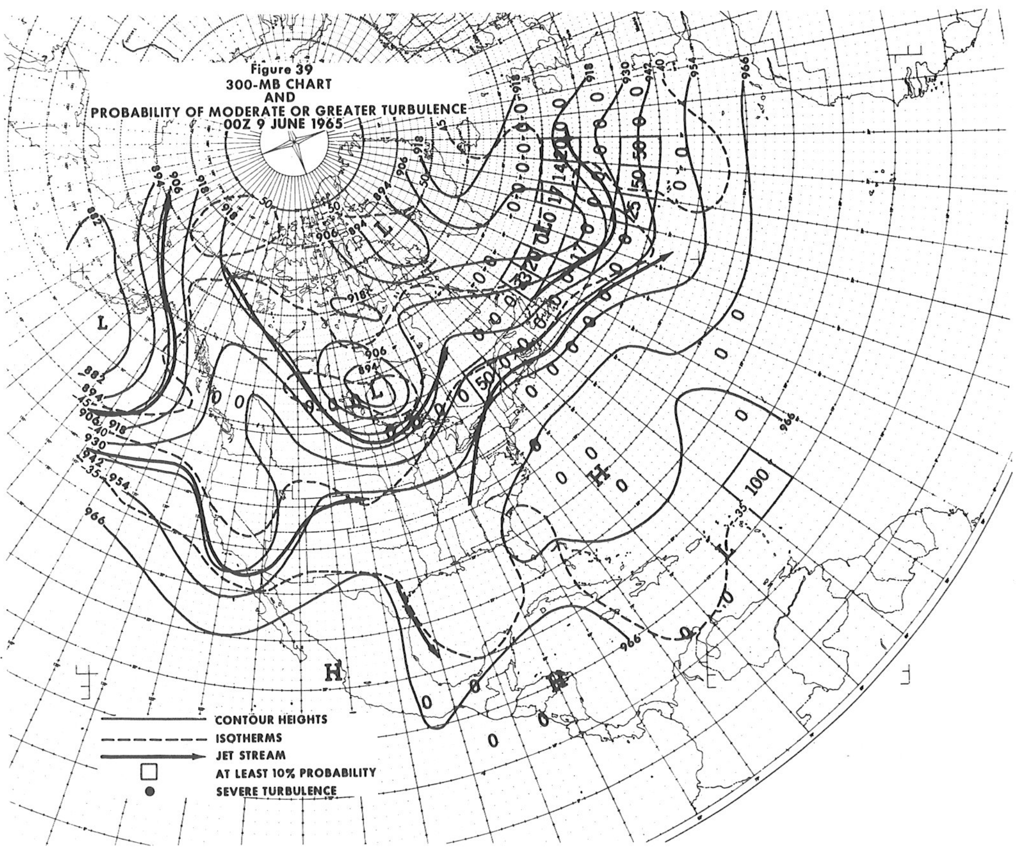
Figure 39
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 9 JUNE 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

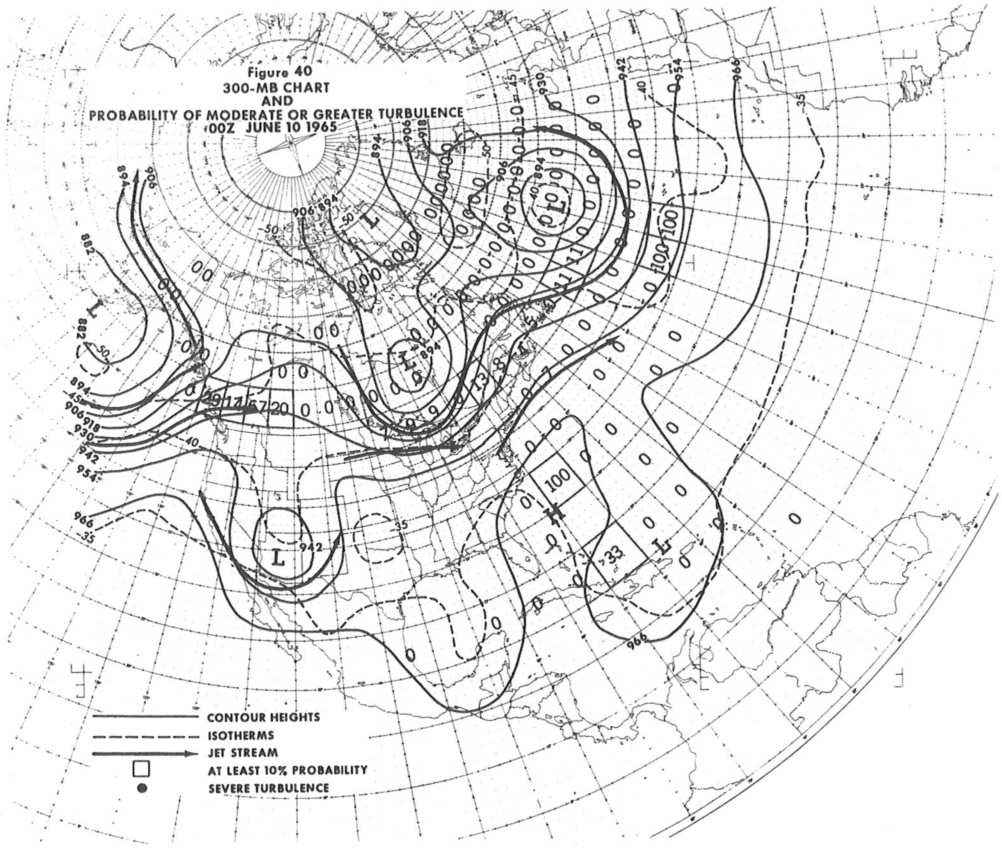
Figure 40
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z JUNE 10 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

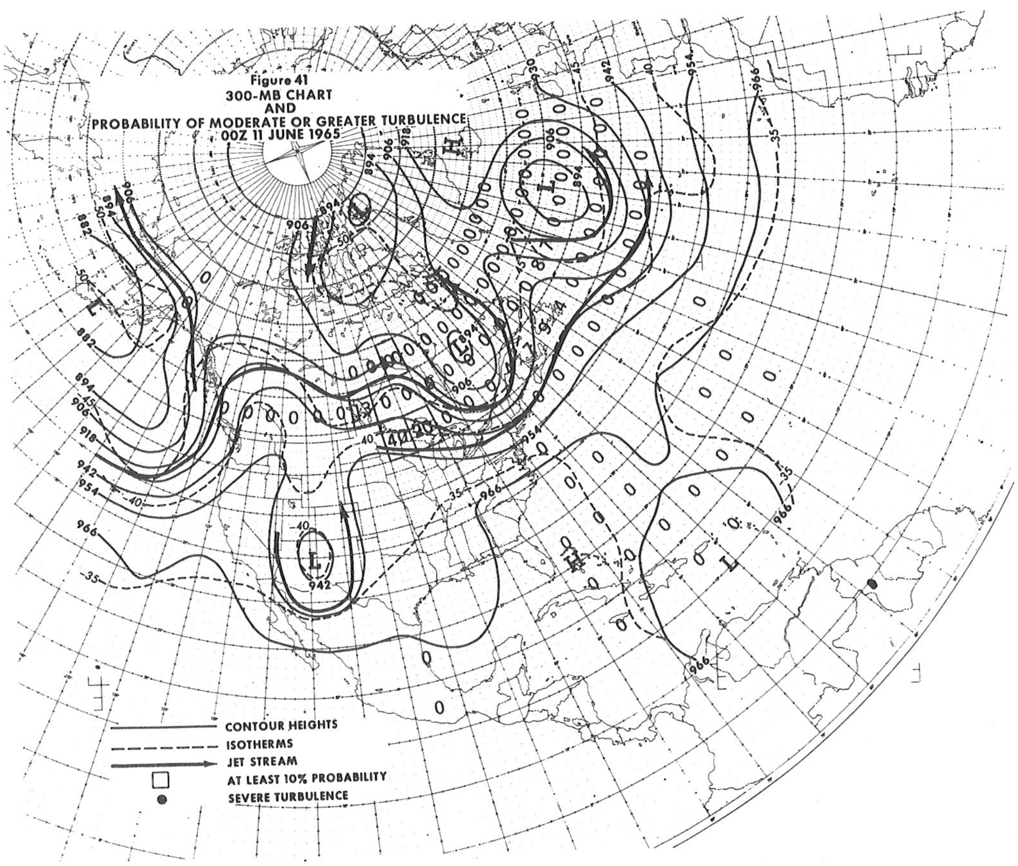
Figure 41
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 11 JUNE 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

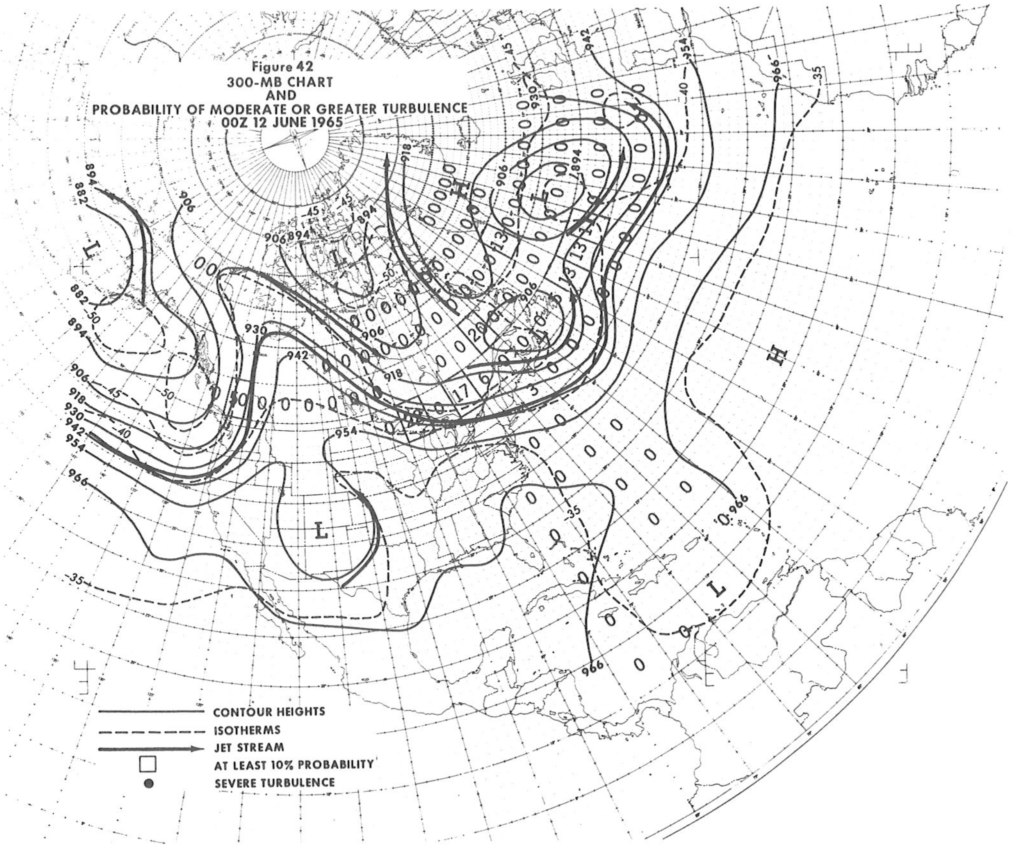
Figure 42
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 12 JUNE 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

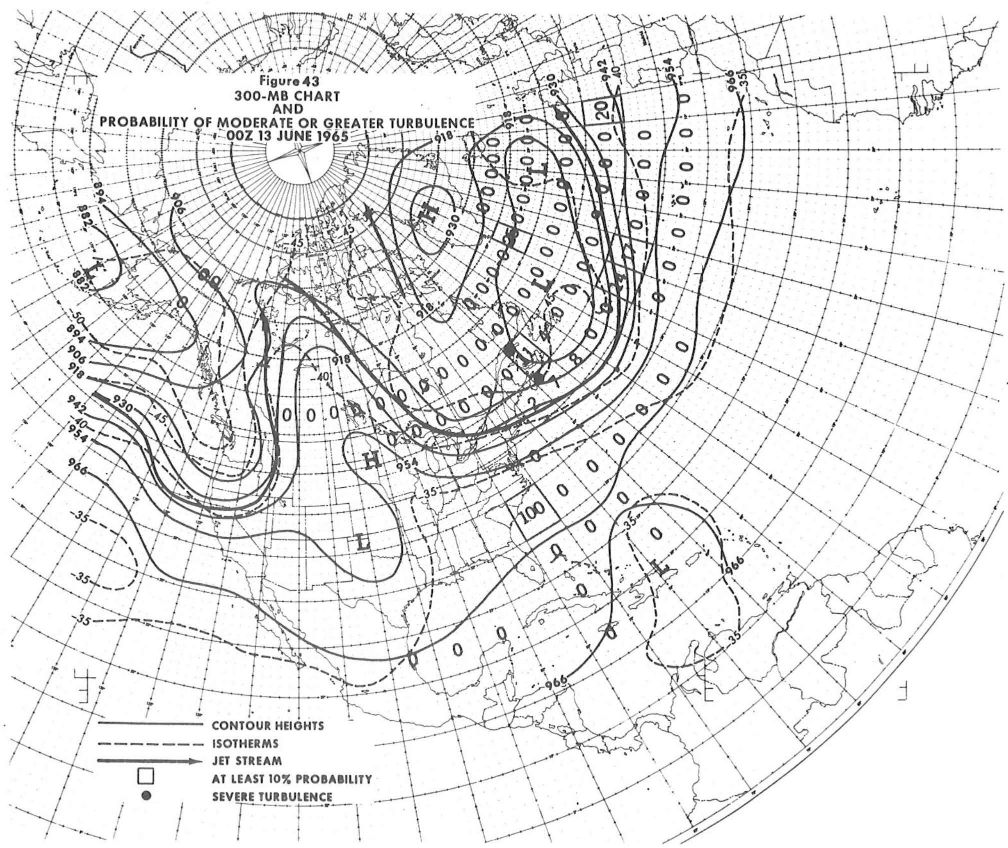
Figure 43
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 13 JUNE 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

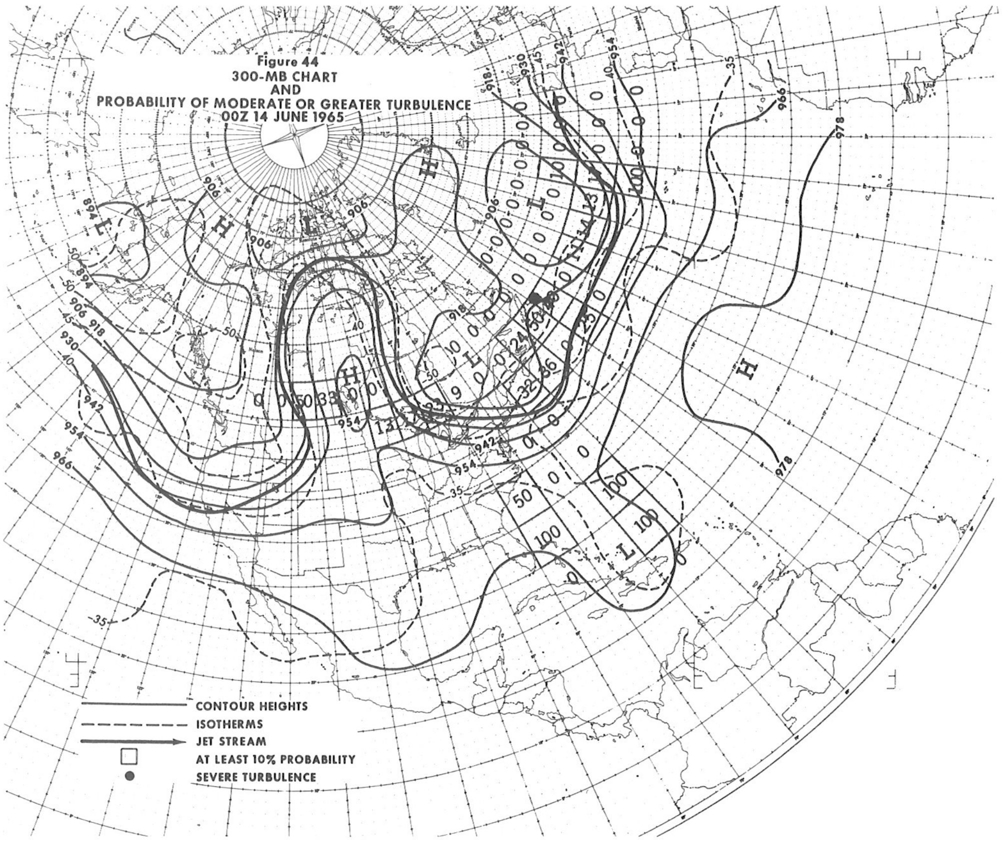
Figure 44
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 14 JUNE 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

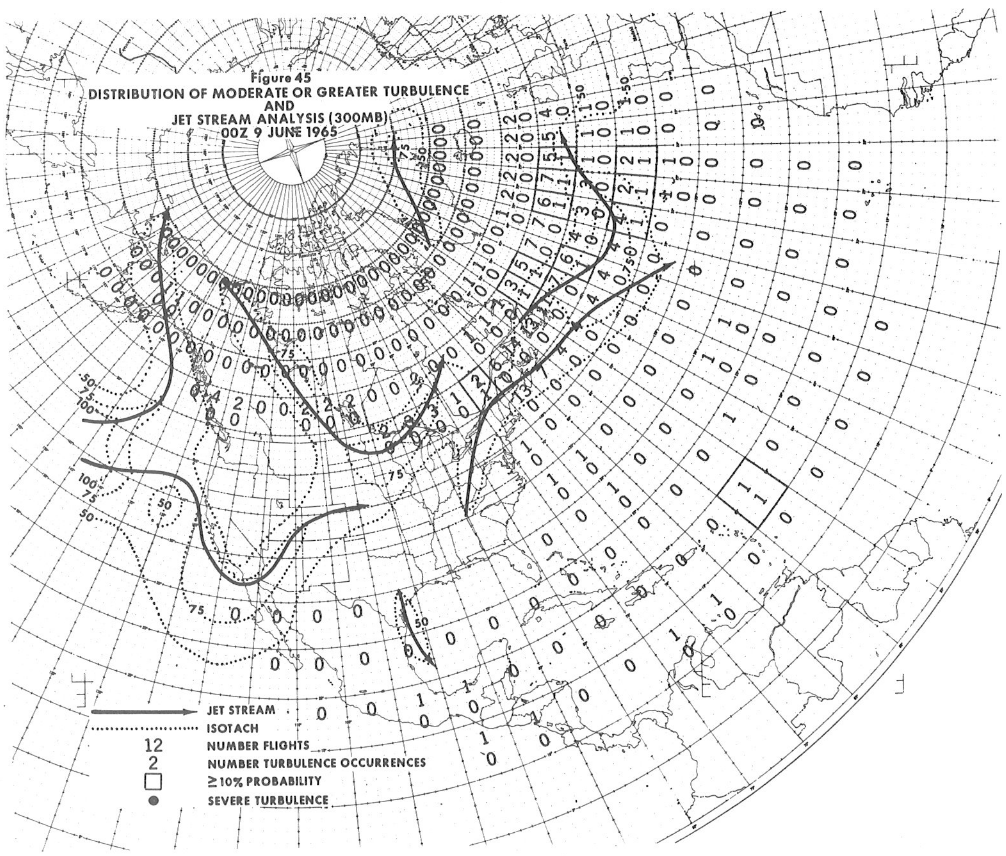
Figure 45
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 9 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

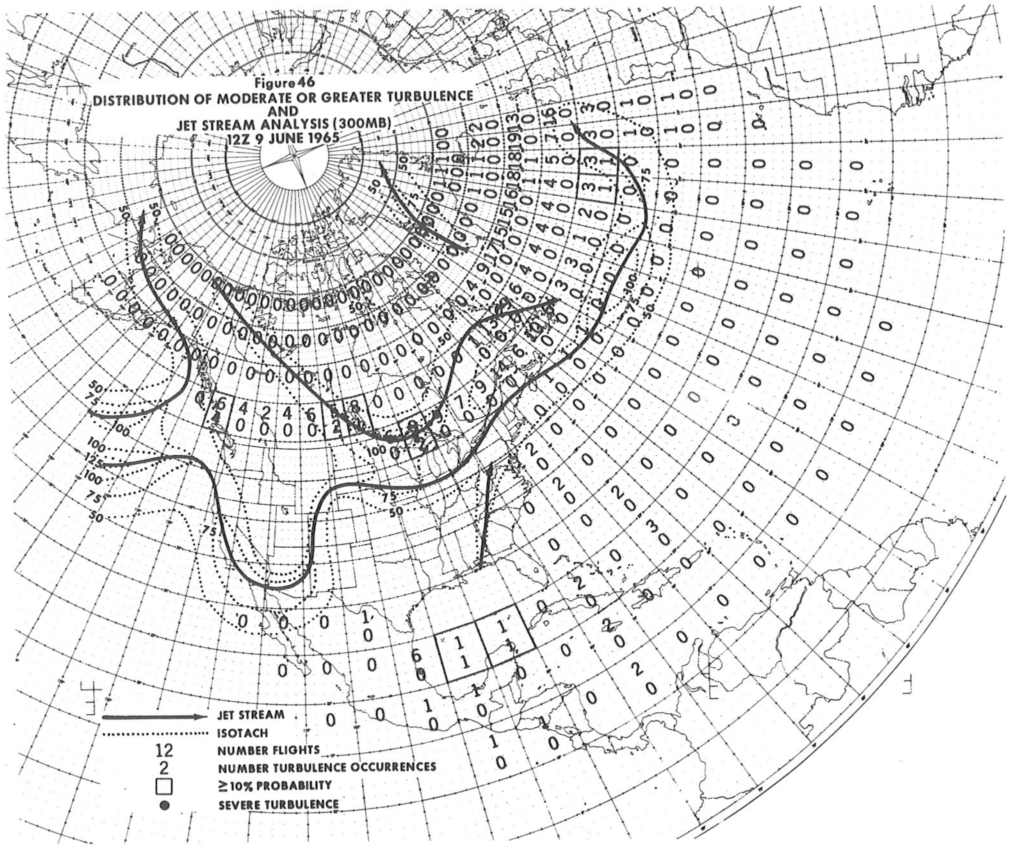
Figure 46
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 9 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

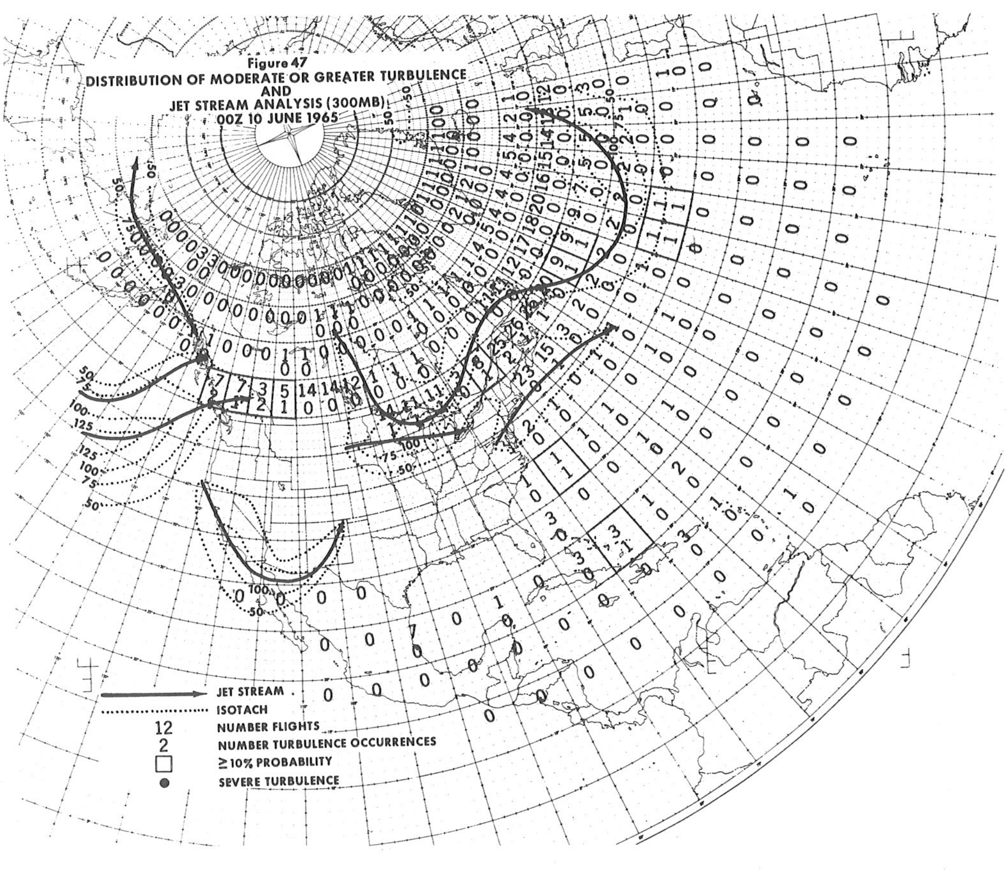
Figure 47
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 10 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

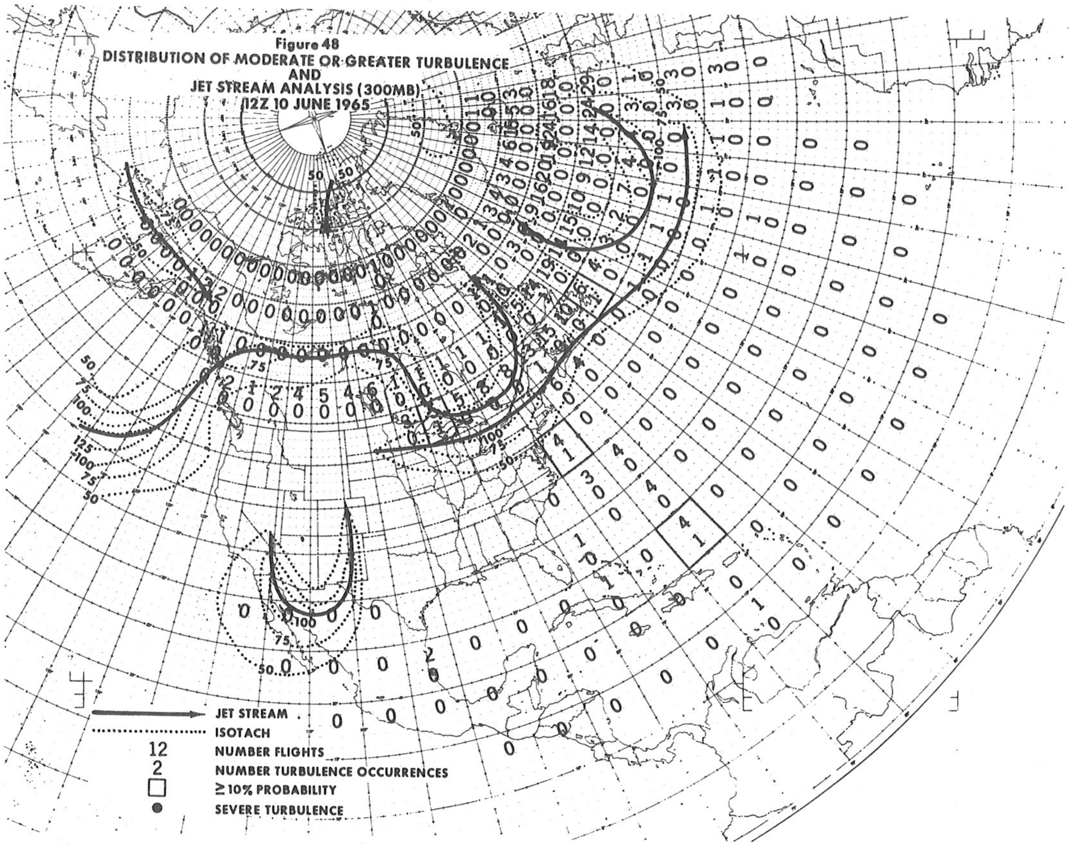
Figure 48
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 10 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

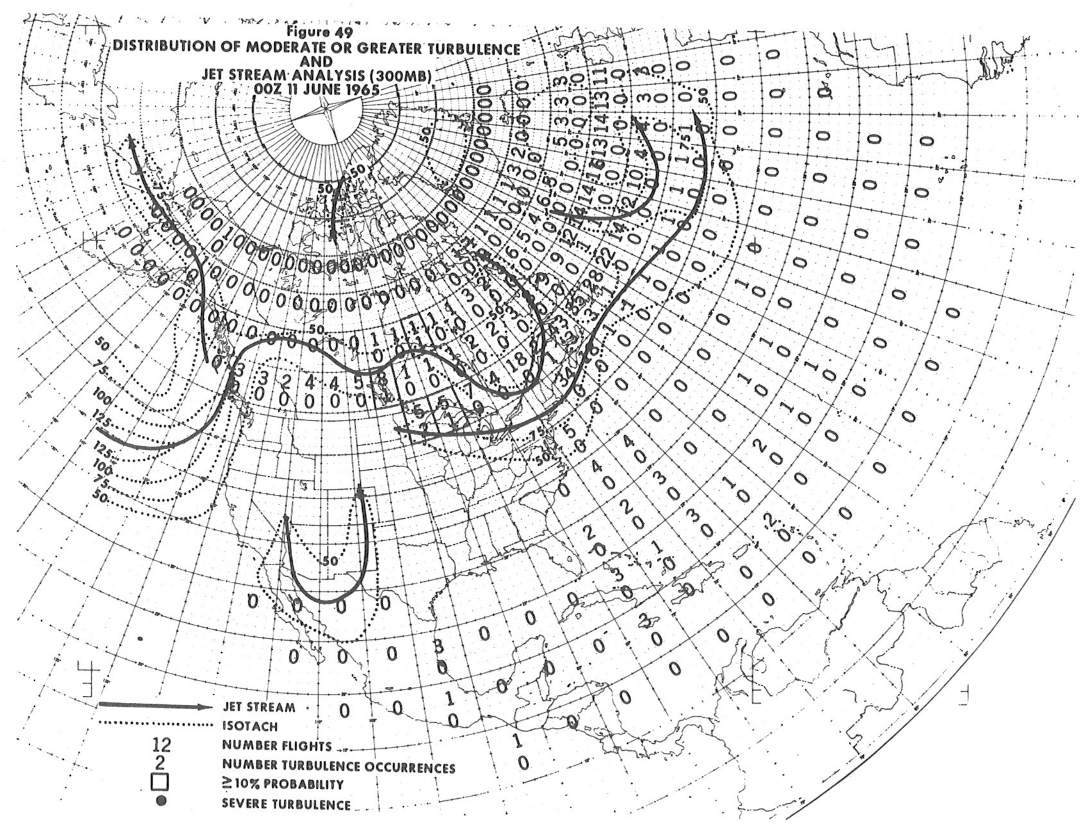
Figure 49
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 11 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

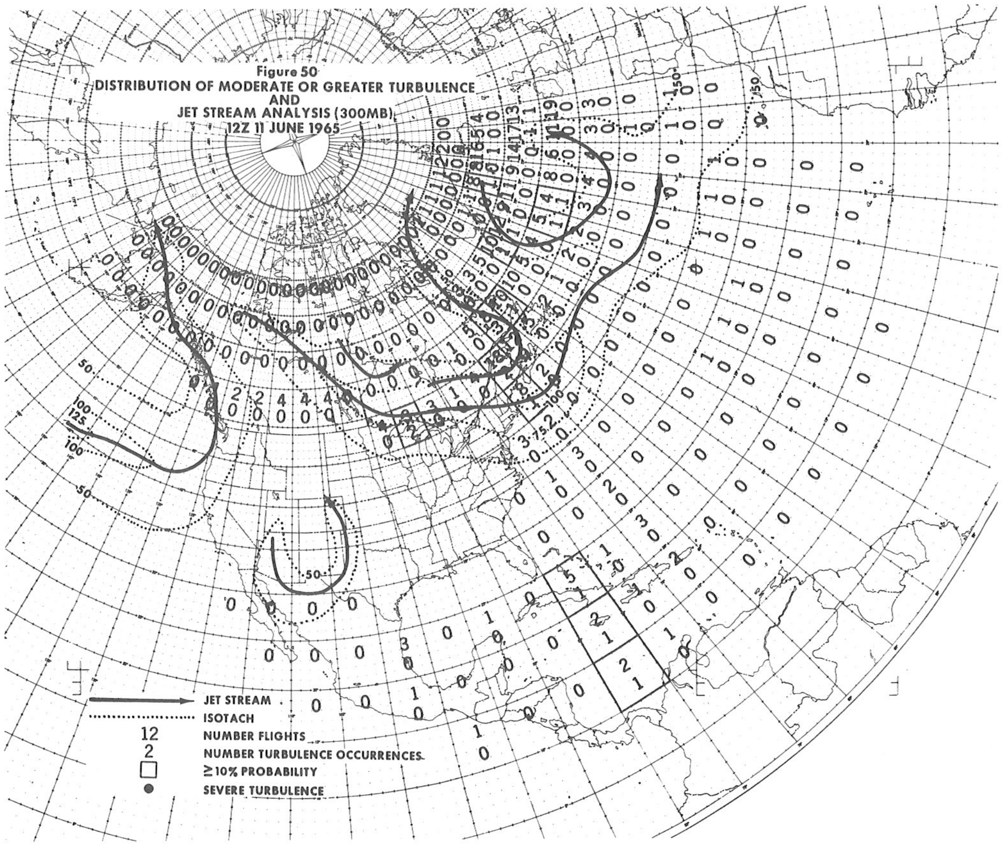
Figure 50
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 11 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

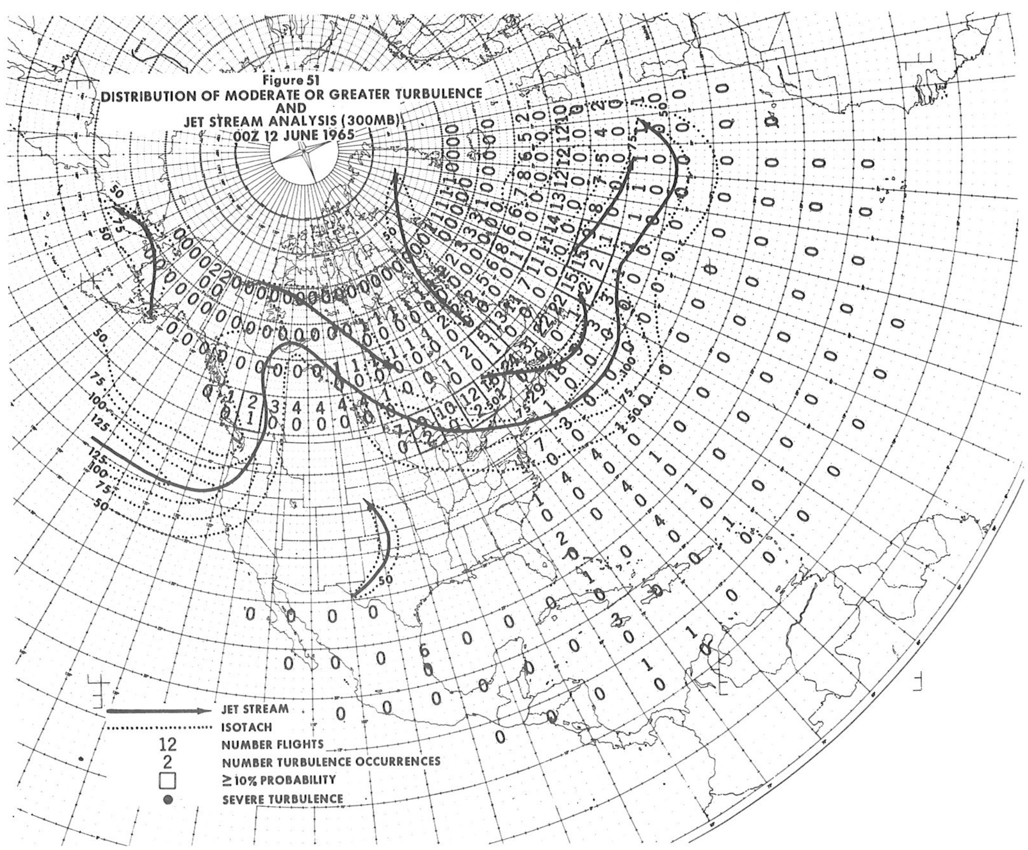
Figure 51
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 12 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

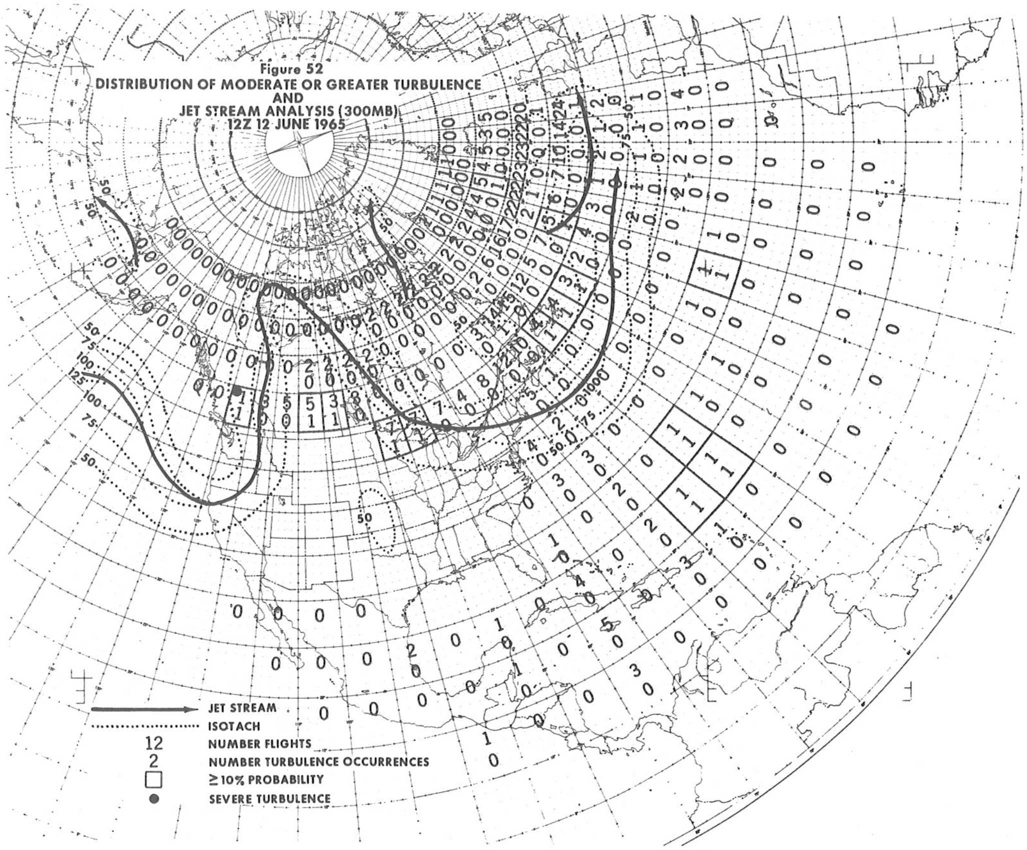

Figure 52
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 12 JUNE 1965

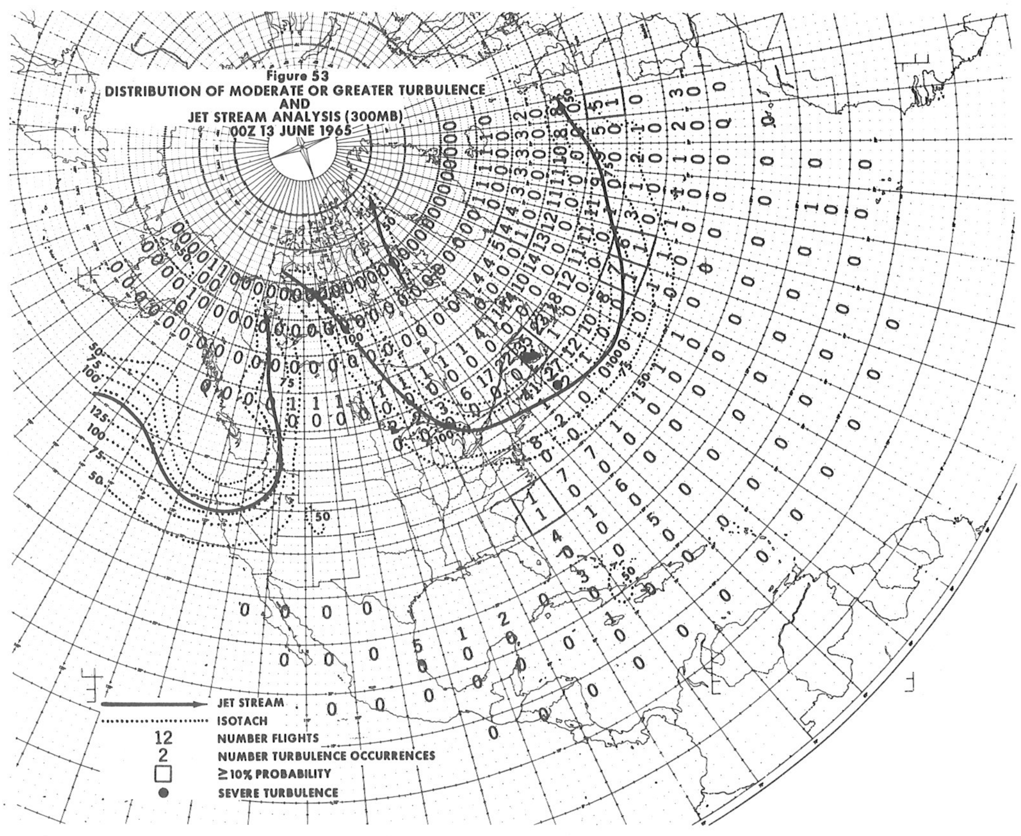

Figure 53
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 13 JUNE 1965

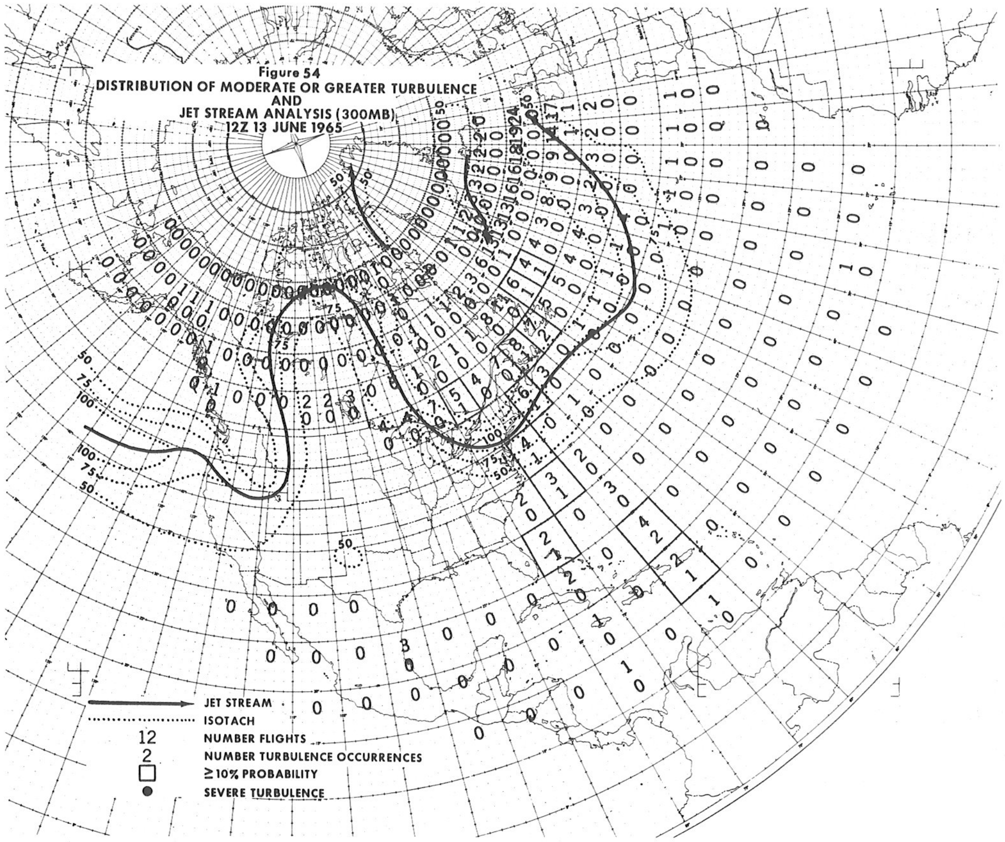
Figure 54
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 13 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

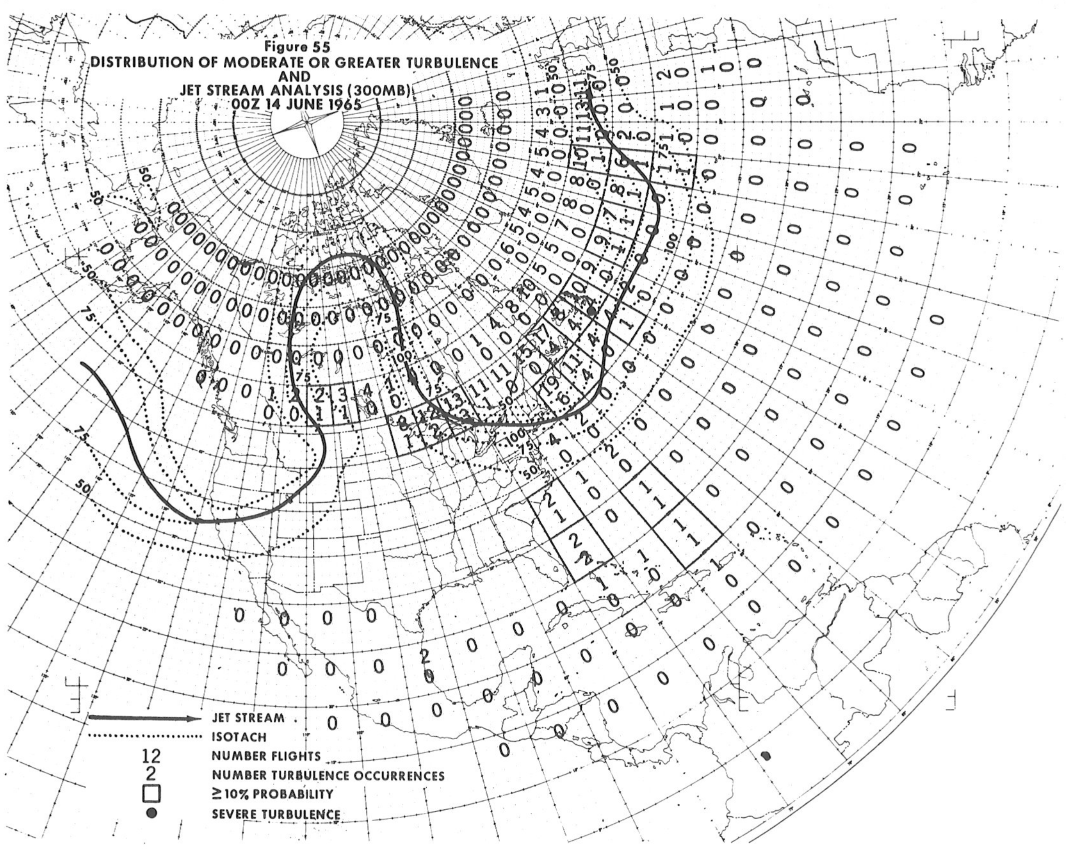
Figure 55
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 14 JUNE 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

V. 8 - 13 SEPTEMBER 1965 DATA COLLECTION PERIOD

A. SUMMARY OF SEPTEMBER DATA

A tabulation of turbulence data for each 12 hour period is shown in Table VII for 8 - 13 September 1965. The overall probability of moderate or greater turbulence for the entire 5-day period was 6 percent over the North Atlantic, 8 percent over ACG, 8 percent over the Caribbean, and 0 percent over Mexico and Central America. In the individual 12 hour periods, the probability of moderate or greater turbulence varied from 1 to 17 percent over the North Atlantic and from 0 to 24 percent over ACG. As in the other data periods, the number of flights was quite small over the Caribbean, mexico and Central America, and the results are not as significant as over the other two areas.

The probability of no turbulence increased and the probability of light or greater turbulence decreased with altitude over both the North Atlantic and ACG. The probability of moderate or greater turbulence over the North Atlantic did not vary much with altitude. The probability of moderate or greater turbulence over ACG was nearly the same in layers A and B but decreased in layer C. The probability of severe turbulence was lower in layer A but showed little change between layers B and C.

The location, altitude, and time of all severe turbulence occurrences are listed in Table VIII; indicating none in layer A, six in layer B, and seven in the top layer. Eleven of the thirteen occurrences were in the 12-hour period centered at 10-0000Z.

Only 29 squares had a total of at least 40 flight squares during the entire period.

B. METEOROLOGICAL ANALYSIS

The mean circulation pattern at the 300-mb level for the entire 5-day period is shown in Fig. 56, along with the probability of moderate or greater turbulence at each square. Squares with high percentages were mostly located between the trough along Nova Scotia and Newfoundland and the high pressure ridge over the central Atlantic. Other high percentage squares were distributed in the zone of strong contour gradients. One noticeable feature was that the region of strong contour gradients was considerably further north than in the June data collection period.

TABLE VII. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 8 - 13 SEPTEMBER 1965

a. NORTH ATLANTIC

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
08-00 Z	134	105	19	10	0	78	22	7	0
-12	183	174	8	1	0	95	5	1	0
09-00	304	253	42	9	0	83	17	3	0
-12	274	245	20	9	0	89	11	3	0
10-00	329	223	49	50	7	68	32	17	2
-12	264	222	26	15	1	84	16	6	<1
11-00	323	239	50	34	0	74	26	11	0
-12	226	198	19	9	0	88	12	4	0
12-00	250	225	16	9	0	90	10	4	0
-12	218	200	10	8	0	92	8	4	0
13-00	180	164	14	2	0	91	9	1	0
TOTAL	2685	2248	273	156	8	84	16	6	<1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SSQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
08-00 Z	0	0	0	0	0	74	53	14	7	0	60	52	5	3	0
-12	6	6	0	0	0	80	73	6	1	0	97	95	2	0	0
09-00	9	9	0	0	0	88	72	14	2	0	207	172	28	7	0
-12	18	16	0	2	0	97	83	10	4	0	159	146	10	3	0
10-00	31	15	13	3	0	117	79	16	19	3	181	129	20	28	4
-12	7	5	2	0	0	81	68	9	4	0	176	149	15	11	1
11-00	4	0	2	2	0	147	104	29	14	0	172	135	19	18	0
-12	22	17	5	0	0	100	84	9	7	0	104	97	5	2	0
12-00	5	3	2	0	0	111	96	7	8	0	134	126	7	1	0
-12	6	6	0	0	0	126	114	5	7	0	86	80	5	1	0
13-00	26	21	5	0	0	77	69	8	0	0	77	74	1	2	0
TOTAL	134	98	29	7	0	1098	895	127	73	3	1453	1255	117	76	5
PERCENT NONE	73					82					86				
≥L	27					18					14				
≥M	5					7					6				
S	0					0.3					0.3				

TABLE VII. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS

8 - 13 SEPTEMBER 1965

b. ALASKA, CANADA AND GREENLAND

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
08-00 Z	74	42	14	18	0	57	43	24	0
-12	42	36	6	0	0	86	14	0	0
09-00	239	198	34	7	0	83	17	3	0
-12	68	48	10	9	1	71	29	15	1
10-00	253	185	35	29	4	73	27	13	2
-12	62	43	14	5	0	69	31	8	0
11-00	173	137	22	14	0	79	21	8	0
-12	56	47	6	3	0	84	16	5	0
12-00	145	135	9	1	0	93	7	1	0
-12	39	35	3	1	0	90	10	3	0
13-00	89	81	7	1	0	91	9	1	0
TOTAL	1240	987	160	88	5	80	20	8	<1

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 St.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SSQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
08-00 Z	18	13	0	5	0	26	10	9	7	0	30	19	5	6	0
-12	0	0	0	0	0	33	28	5	0	0	9	8	1	0	0
09-00	23	18	5	0	0	109	84	18	7	0	107	96	11	0	0
-12	6	4	0	2	0	26	15	3	-	1	36	29	7	0	0
10-00	33	20	10	3	0	105	71	12	20	2	115	94	13	6	2
-12	7	4	3	0	0	19	9	5	5	0	36	30	6	0	0
11-00	5	3	2	0	0	76	60	7	9	0	92	74	13	5	0
-12	4	3	1	0	0	20	16	3	1	0	32	28	2	2	0
12-00	8	8	0	0	0	86	76	9	1	0	51	51	0	0	0
-12	5	4	0	1	0	16	16	0	0	0	18	15	3	0	0
13-00	6	3	2	1	0	48	44	4	0	0	35	34	1	0	0
TOTAL	115	80	23	12	0	564	429	75	57	3	561	478	62	19	2
PERCENT NONE	70					76					85				
≥L	30					24					15				
≥M	10					11					4				
S	0					0.5					0.4				

TABLE VII. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS 8 - 13 SEPTEMBER 1965

c. CARIBBEAN

DATE -TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	PERCENT WITH NONE	≥L	≥M	S
08-00 Z	0	0	0	0	0	100	0	0	0
-12	7	7	0	0	0	100	0	0	0
09-00	2	2	0	0	0	100	0	0	0
-12	3	3	0	0	0	100	0	0	0
10-00	4	4	0	0	0	100	0	0	0
-12	5	5	0	0	0	100	0	0	0
11-00	20	14	2	4	0	70	30	20	0
-12	4	2	1	1	0	50	50	25	0
12-00	14	14	0	0	0	100	0	0	0
-12	0	0	0	0	0	0	0	0	0
13-00	3	3	0	0	0	100	0	0	0
TOTAL	62	54	3	5	0	87	13	8	0

FURTHER DISTRIBUTION BY LAYERS

	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY NONE	L	M	S
08-00 Z	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-12	0	0	0	0	0	2	2	0	0	0	5	5	0	0	0
09-00	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0
-12	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0
10-00	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0
-12	1	1	0	0	0	1	1	0	0	0	3	3	0	0	0
11-00	0	0	0	0	0	12	8	2	2	0	8	6	0	2	0
-12	3	1	1	1	0	1	1	0	0	0	0	0	0	0	0
12-00	1	1	0	0	0	5	5	0	0	0	8	8	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13-00	1	1	0	0	0	1	1	0	0	0	1	1	0	0	0
TOTAL	6	4	1	1	0	30	26	2	2	0	26	24	0	2	0
PERCENT NONE	67					87					92				
≥L	33					13					8				
≥M	17					7					8				
S	0					0					0				

TABLE VII. DISTRIBUTION OF TURBULENCE BY 12-HOUR PERIODS — 8 - 13 SEPTEMBER 1965

d. MEXICO AND CENTRAL AMERICA

DATE-TIME	TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S	PERCENT WITH: NONE	≥L	≥M	S
08-00 Z	1	1	0	0	0	100	0	0	0
-12	4	4	0	0	0	100	0	0	0
09-00	5	5	0	0	0	100	0	0	0
-12	2	2	0	0	0	100	0	0	0
10-00	5	5	0	0	0	100	0	0	0
-12	3	3	0	0	0	100	0	0	0
11-00	7	6	1	0	0	86	14	0	0
-12	3	3	0	0	0	100	0	0	0
12-00	4	4	0	0	0	100	0	0	0
-12	4	4	0	0	0	100	0	0	0
13-00	5	5	0	0	0	100	0	0	0
TOTAL	43	42	1	0	0	98	2	0	0

FURTHER DISTRIBUTION BY LAYERS

DATE-TIME	A (BELOW 30,000 Ft.) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S	B (30,000-33,999 Ft.) TOTAL FLIGHT SSQUARES	NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S	C (34,000 Ft. AND ABOVE) TOTAL FLIGHT SQUARES	NUMBER OCCURRENCES OF INTENSITY: NONE	L	M	S
08-00 Z	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
-12	0	0	0	0	0	1	1	0	0	0	3	3	0	0	0
09-00	0	0	0	0	0	1	1	0	0	0	4	4	0	0	0
-12	0	0	0	0	0	1	1	0	0	0	1	1	0	0	0
10-00	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0
-12	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0
11-00	0	0	0	0	0	2	1	1	0	0	5	5	0	0	0
-12	0	0	0	0	0	1	1	0	0	0	2	2	0	0	0
12-00	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0
-12	0	0	0	0	0	1	1	0	0	0	3	3	0	0	0
13-00	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0
TOTAL	0	0	0	0	0	7	6	1	0	0	36	36	0	0	0

	A	B	C
PERCENT NONE	0	86	100
≥L	0	14	0
≥M	0	0	0
S	0	0	0

TABLE VIII. LOCATION OF SEVERE TURBULENCE OCCURRENCES 8 - 13 Sept. 1965

Sept. 1965

DATE-TIME	SQUARE	LAYER	LOCATION
09-1200Z	129	B	Canada
10-0000Z	112	B	Canada
10-0000Z	112	B	Canada
10-0000Z	112	C	Canada
10-0000Z	112	C	Canada
10-0000Z	113	B	N. Atlantic
10-0000Z	113	B	N. Atlantic
10-0000Z	113	C	N. Atlantic
10-0000Z	113	C	N. Atlantic
10-0000Z	114	B	N. Atlantic
10-0000Z	115	C	N. Atlantic
10-0000Z	116	C	N. Atlantic
10-1200Z	92	C	N. Atlantic

The daily sequence of 300-mb circulation patterns is shown in Figures 57 - 62 at the 0000Z synoptic time each day. At the beginning of the 5-day period, as illustrated by the 8-0000Z 300-mb chart (Fig. 57), a series of three main low pressure centers was present north of 45° latitude. The deepest center was located over the northern end of Hudson Bay. In addition, two cut-off lows were present in western United States and in the western Atlantic. A major jet stream and associated strong contour gradient extended from the Alaska coast around the southern portions of the major low pressure systems.

By 9-0000Z (Fig. 58), the low centers over Alaska and Canada had merged into one larger system. The high pressure ridge between this low and the one over Ireland intensified with increasing curvature of the flow patterns. The chart for 10-0000Z (Fig. 59) indicated strong cyclogenesis in the region between Labrador and the southern tip of Greenland. The contour gradients and curvature of the flow patterns around this low and the intensifying high pressure ridge increased considerably. During the next 24 hours, as illustrated by the 11-0000Z 300-mb chart (Fig. 60), the low moved to a position over the southern portion of Greenland, and the high pressure ridge was displaced almost 15 degrees eastward. The contour gradient and curvature of the flow patterns had weakened decidedly. The flow west of 35°W longitude had now become more nearly west to east. During the next 48 hours, 12-0000Z and 13-0000Z 300-mb charts (Figures 61 and 62), the situation did not change materially. Throughout the entire 5-day period, the area south of 45°N latitude was characterized by weak and flat pressure systems.

The number of flights and the number of moderate or greater turbulence occurrences at each square are shown with the 300-mb jet streams and isotachs at each 12-hour synoptic map time in Figures 63 - 73. Squares with at least 10 percent probability of moderate or greater turbulence are outlined, and the squares with severe turbulence occurrences are marked.

In the first 12-hour period centered at 8-0000Z (Figures 57 and 63), most of the turbulence occurred in southeast Canada. The southern portion was a region of sharply divergent flow, and the northern portion was near an exit zone of a 100 knot isotach and in the stronger contour gradient zone. Some turbulence was reported in the eastern Atlantic near the other 100-knot isotachs along the major jet stream. Only a few reports of widely scattered turbulence were indicated on the 08-1200Z 300-mb chart (Fig. 64).

The chart for 9-0000Z (Figures 58 and 65) still indicated only a few widely scattered reports of turbulence. Most of the reports were in a divergence zone south of Nova Scotia and in the increasingly curved flow patterns between the low and the intensifying high pressure ridge. A 125-knot isotach was present south of Iceland, but no turbulence was reported in this region. Turbulence increased considerably during the next 12-hour period centered at 09-1200Z (Fig. 66), and was concentrated in an area from Nova Scotia eastward. The curvature of the flow had sharpened greatly as the low center moved eastward and the high pressure ridge intensified, and the contour gradients increased considerably. One square along the region of sharpest curvature had severe turbulence.

One of the more interesting periods is shown at 10-0000Z (Figures 59 and 67), which showed a decided increase in the number of moderate or greater turbulence occurrences and the number of 10 percent squares. Five squares had a total of eleven reports of severe turbulence. A low pressure center developed between Labrador and Greenland, with strongly curved flow around this center and the intensified high pressure ridge to the east. The jet stream analysis indicated a 100-knot isotach and strong horizontal wind shear. Some turbulence was reported between the 100-knot isotachs north of the Great Lakes and in the divergence pattern off New England and Nova Scotia.

On the 10-1200Z 300-mb chart (Fig. 68), the turbulence was located in this divergence zone and in the strongly curved flow around the low center and the adjoining high pressure ridge. One report of severe turbulence occurred near the region of strongest curvature and the exit zone of the 100-knot isotach.

The turbulence during the next period centered at 11-0000Z (Figures 60 and 69) was largely concentrated between 45 and 55°N latitude and west of 25°W longitude. The high pressure ridge had been displaced about 15 degrees eastward, and the curvature of the flow pattern around the low pressure system decreased west of 35°W longitude. Turbulence was concentrated in the divergence zone off Nova Scotia and to the south of the major jet stream. Wind speeds and horizontal wind shears as well as the contour gradients had decreased considerably from the last period.

During the next 12-hour period, illustrated by the 11-1200Z 300-mb chart (Fig. 70), turbulence had decreased somewhat. One major area of turbulence was along the 100-knot isotach over southeast Canada. Other reports, located over the eastern Atlantic, were difficult to explain since the values of wind speed, wind shear, and contour gradient were quite low in this area.

The charts for 12-0000Z, as seen in Figures 61 and 71, indicated little turbulence in any region. A few turbulence reports were shown off Nova Scotia in a possible weak divergence area. Most of the turbulence indicated on the 12-1200Z 300-mb chart (Fig. 72) occurred in the region south of Greenland as the air flowed around the low pressure center redeveloping southwest of Greenland. Another area of turbulence occurred over the Central Atlantic south of 45°N latitude which was difficult to explain.

The last 12-hour period centered at 13-0000Z (Figures 62 and 73) indicated little turbulence. In general, the winds, wind shears, and contour gradients had weakened across the Atlantic. Unfortunately, in the vicinity of the 100-knot isotach and reasonably strong wind shear north of the Great Lakes, there were practically no flights.

During the entire 5-day period, the zones of active pressure systems, high winds, large wind shears, strong contour gradients, and sharply curved flow patterns were further north than during the June period. Since this was in the latitude range of more international flights, this might be one explanation of the larger number and greater probability of turbulence during this September period.

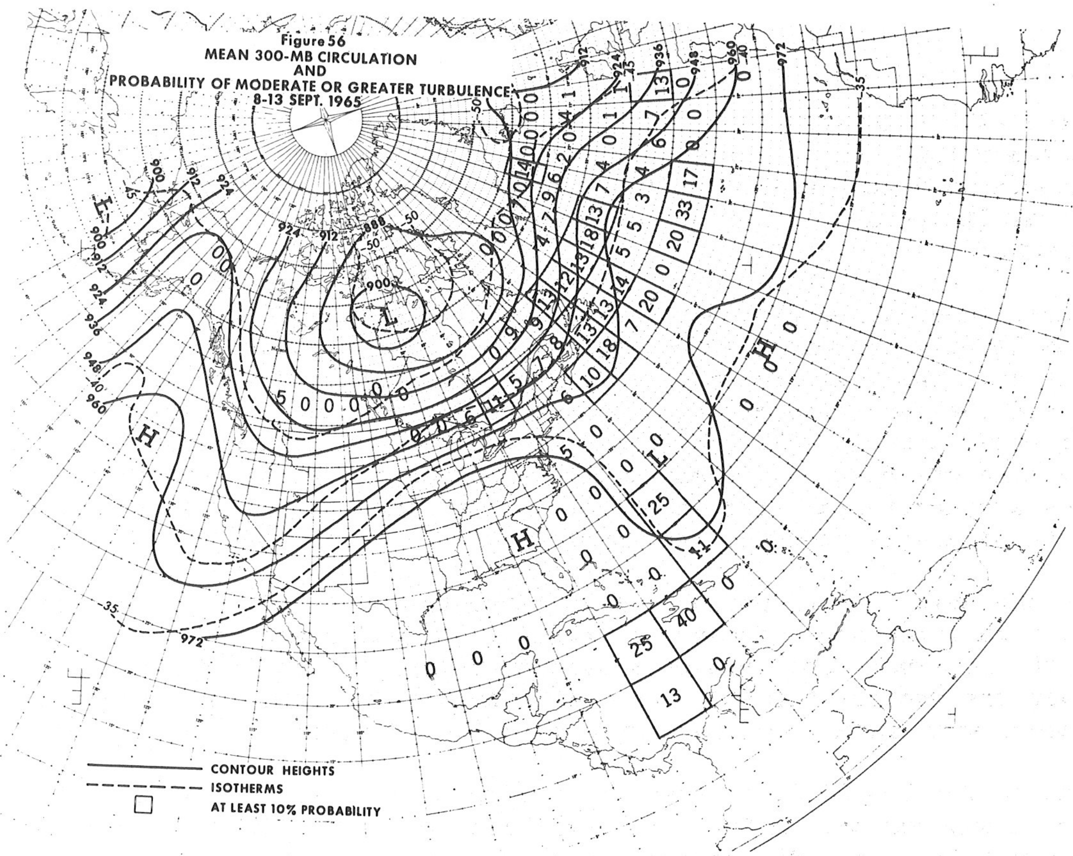

Figure 56
MEAN 300-MB CIRCULATION
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
8-13 SEPT. 1965

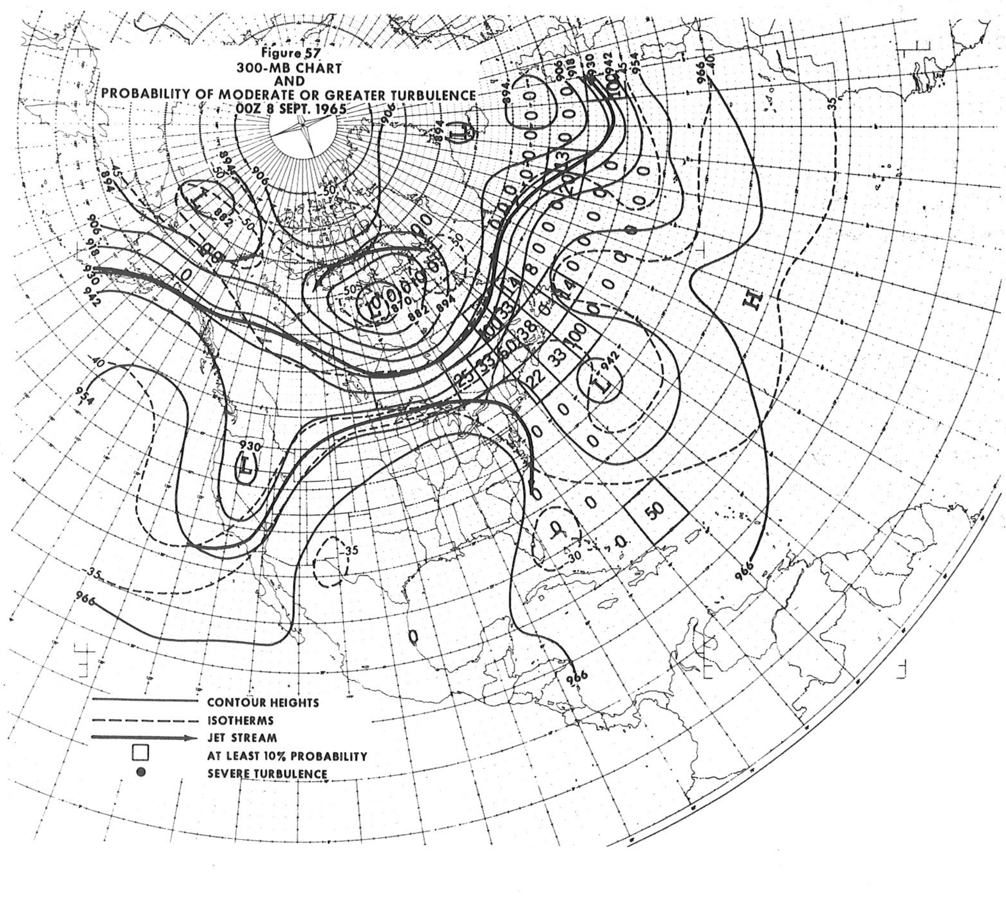

Figure 57
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 8 SEPT. 1965

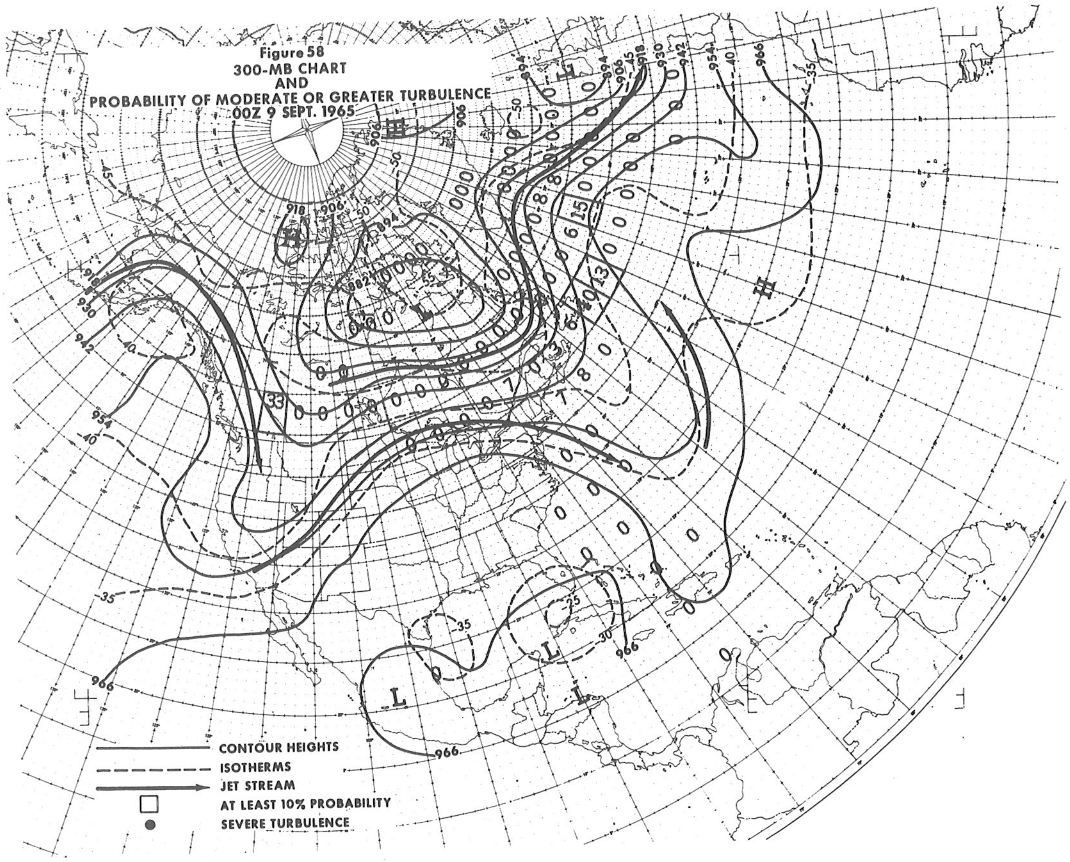

Figure 58
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 9 SEPT. 1965

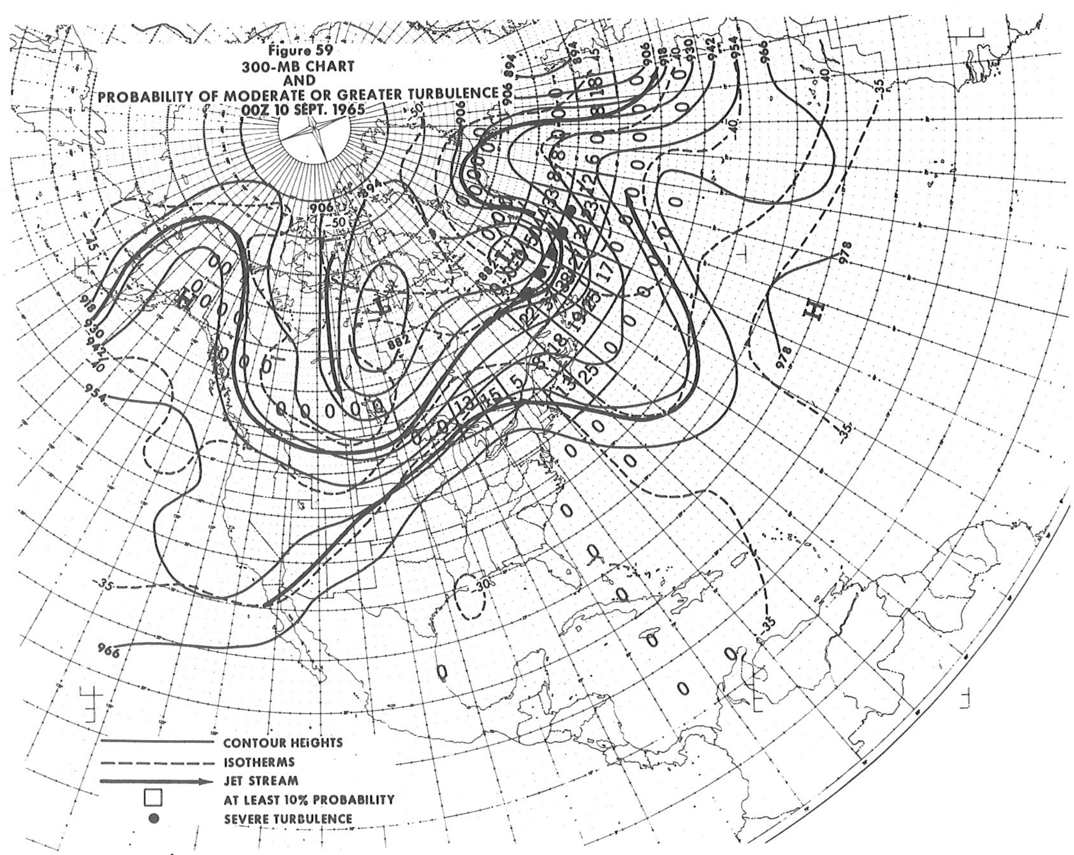

Figure 59
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 10 SEPT. 1965

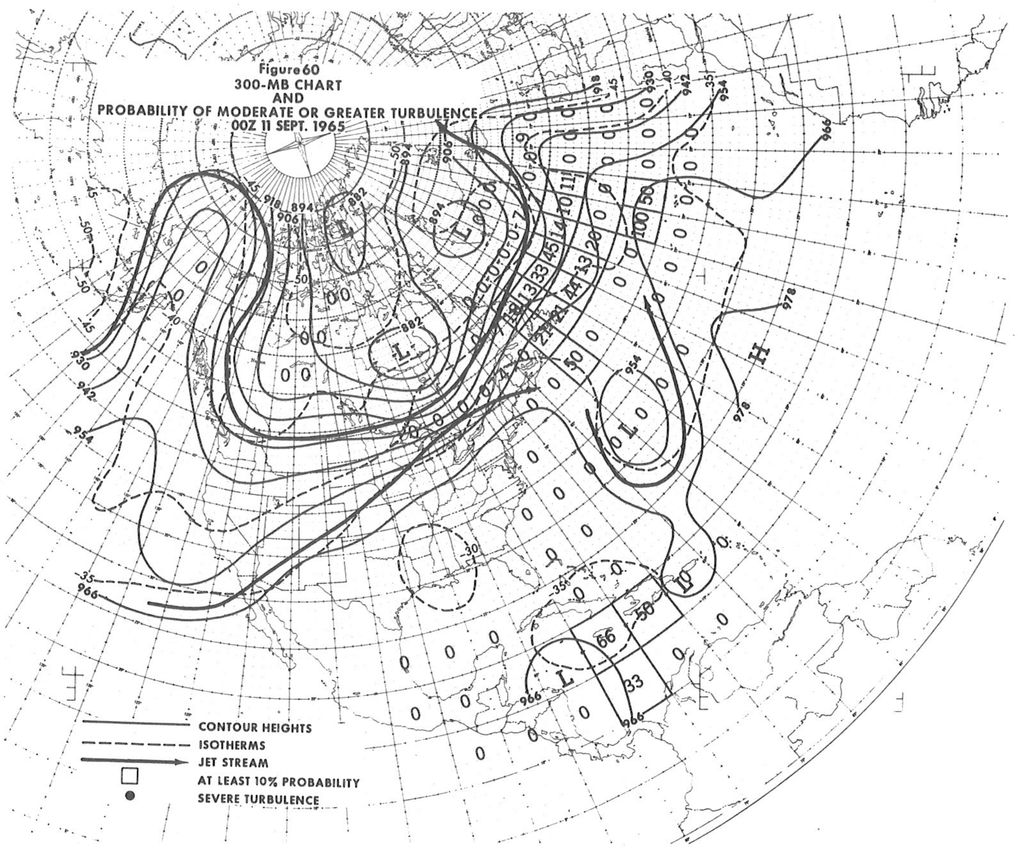
Figure 60
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 11 SEPT. 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

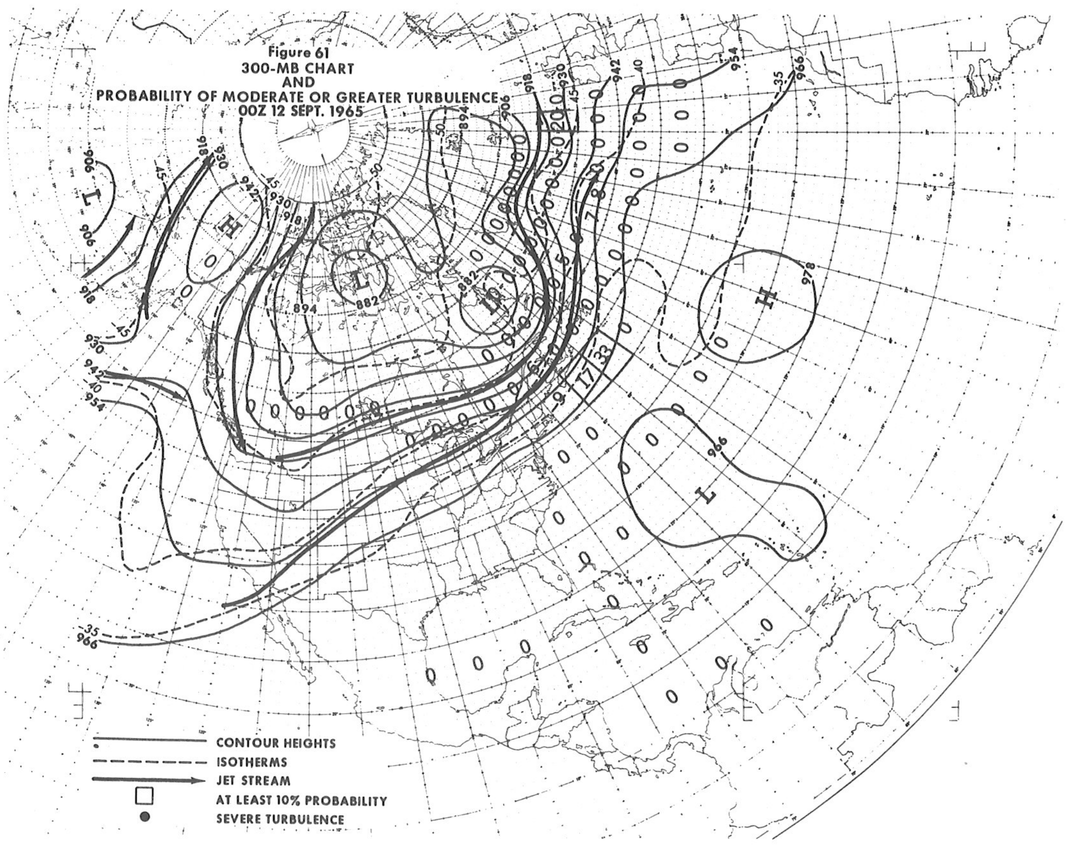
Figure 61
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 12 SEPT. 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

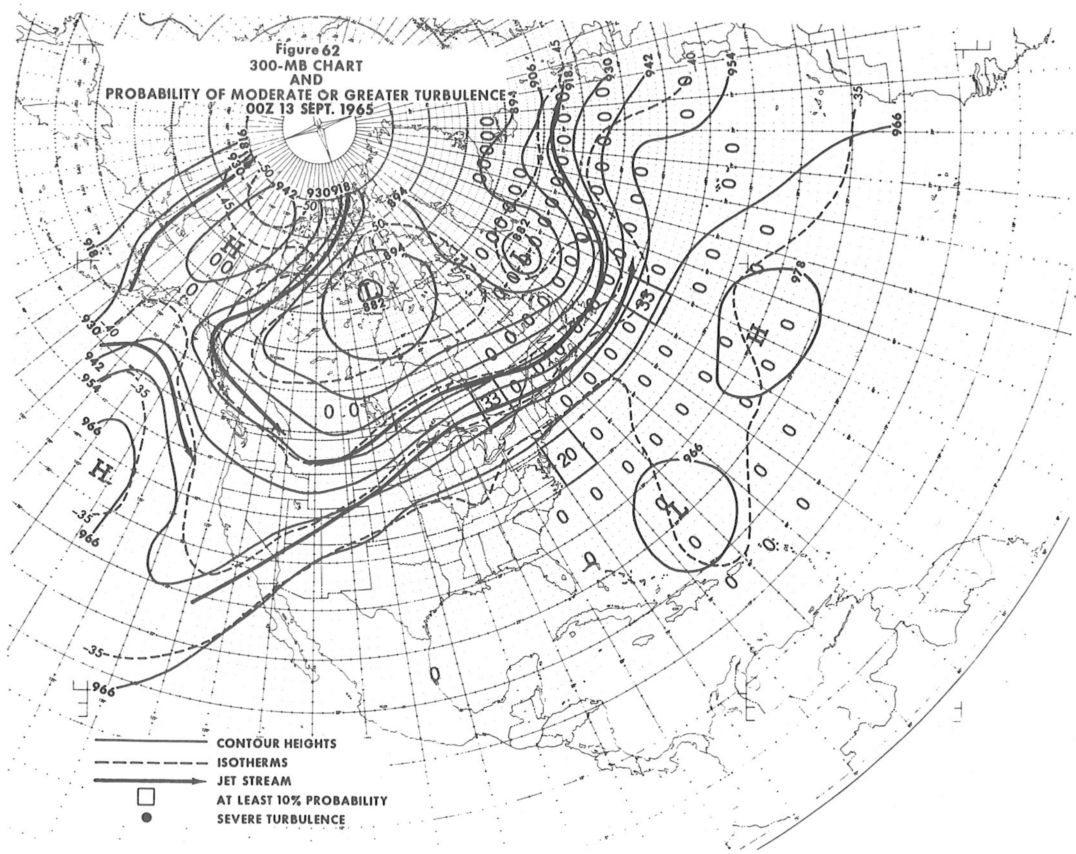
Figure 62
300-MB CHART
AND
PROBABILITY OF MODERATE OR GREATER TURBULENCE
00Z 13 SEPT. 1965
CONTOUR HEIGHTS
ISOTHERMS
JET STREAM
AT LEAST 10% PROBABILITY
SEVERE TURBULENCE

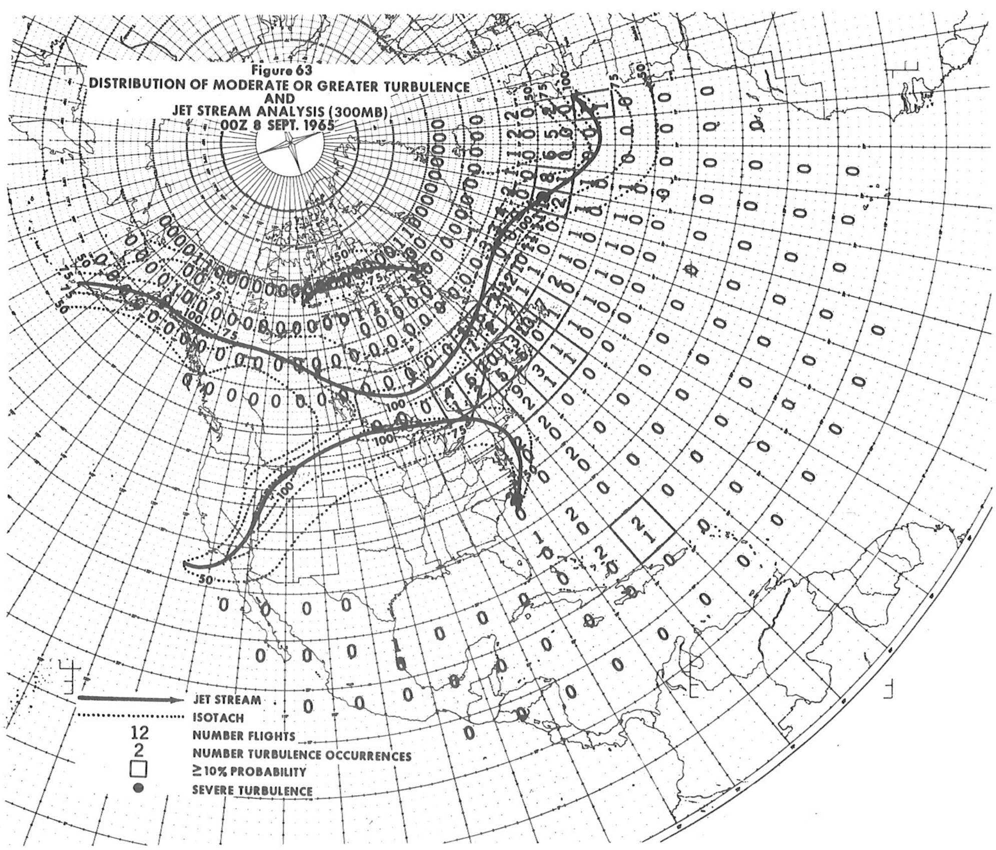
Figure 63
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 8 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

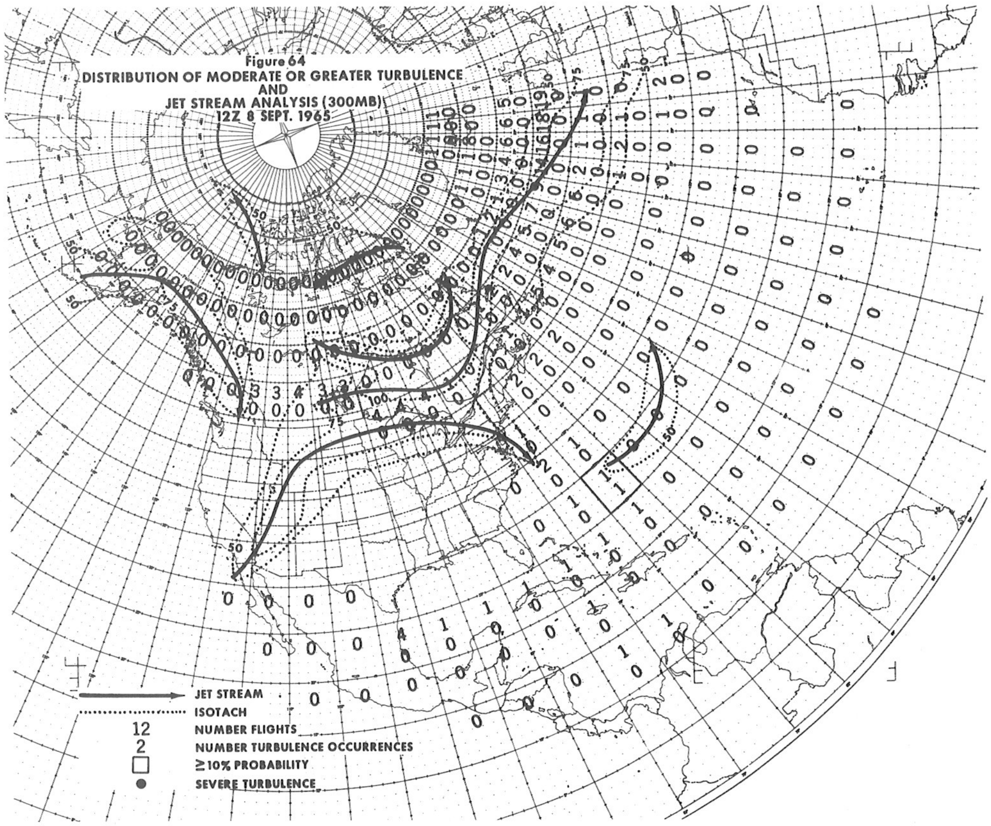
Figure 64
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 8 SEPT. 1965
JET STREAM
ISOTACH
12
NUMBER FLIGHTS
2
NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

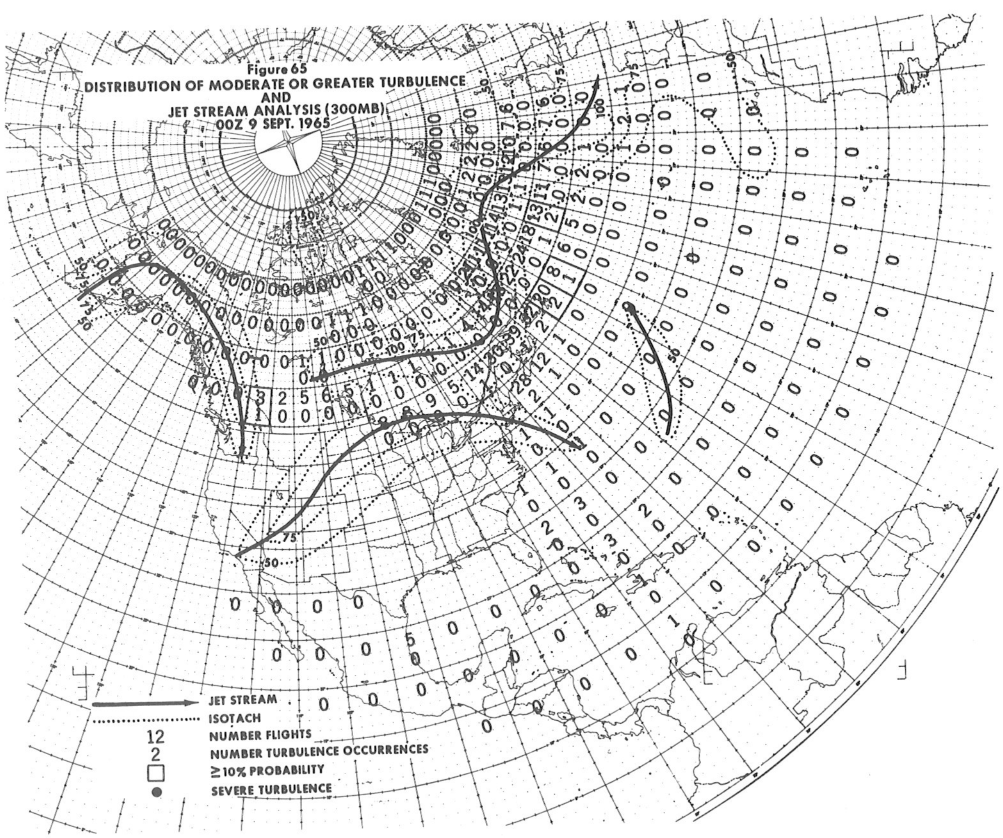
Figure 65
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 9 SEPT. 1965
JET STREAM
ISOTACH
12
NUMBER FLIGHTS
2
NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

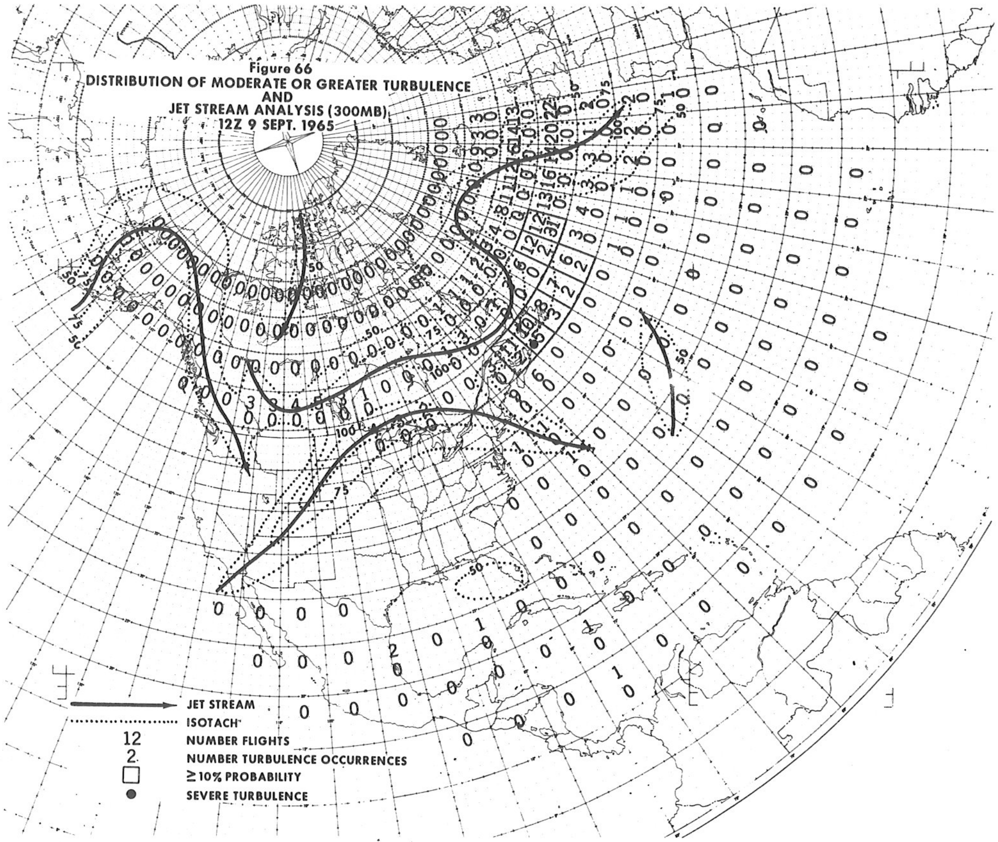
Figure 66
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 9 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

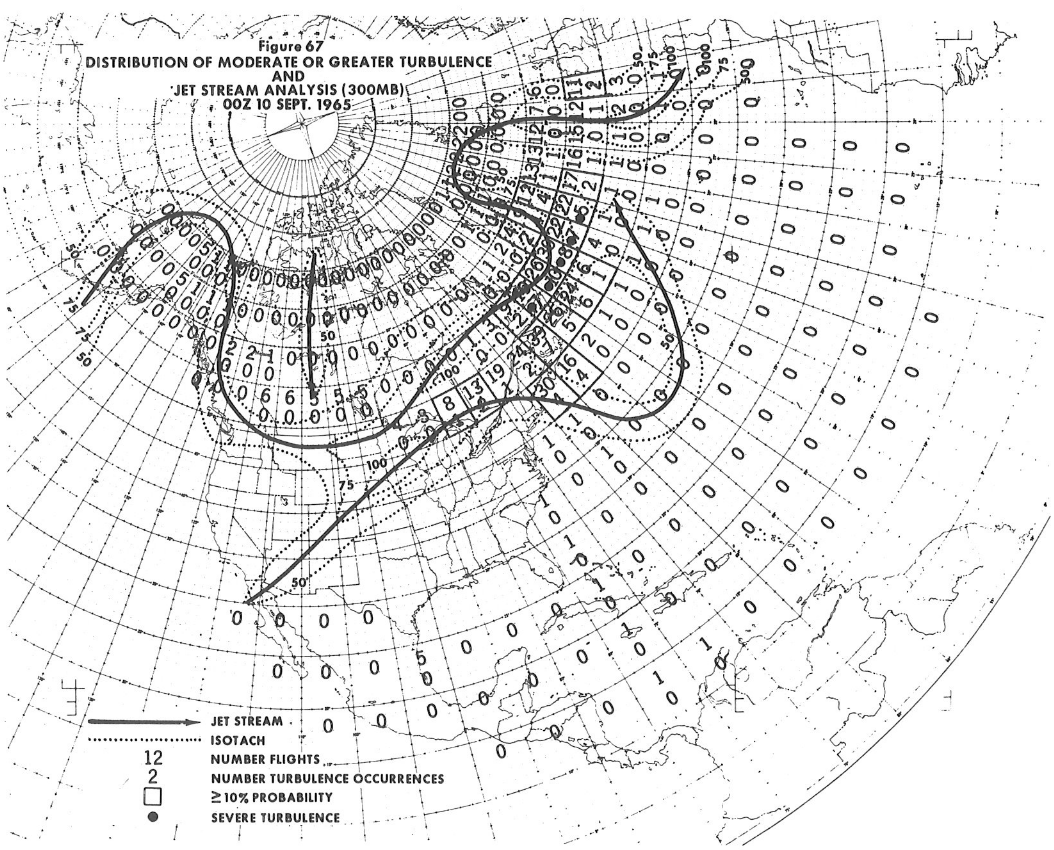
Figure 67
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 10 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

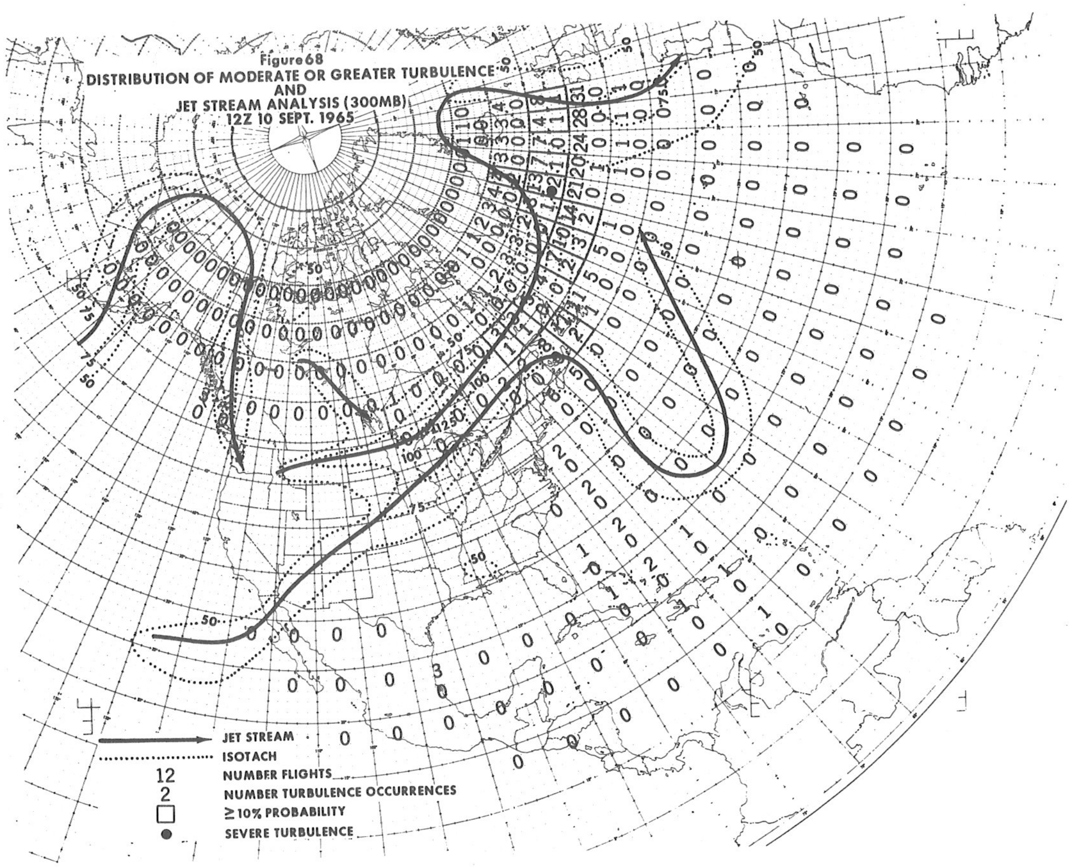
Figure 68
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 10 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

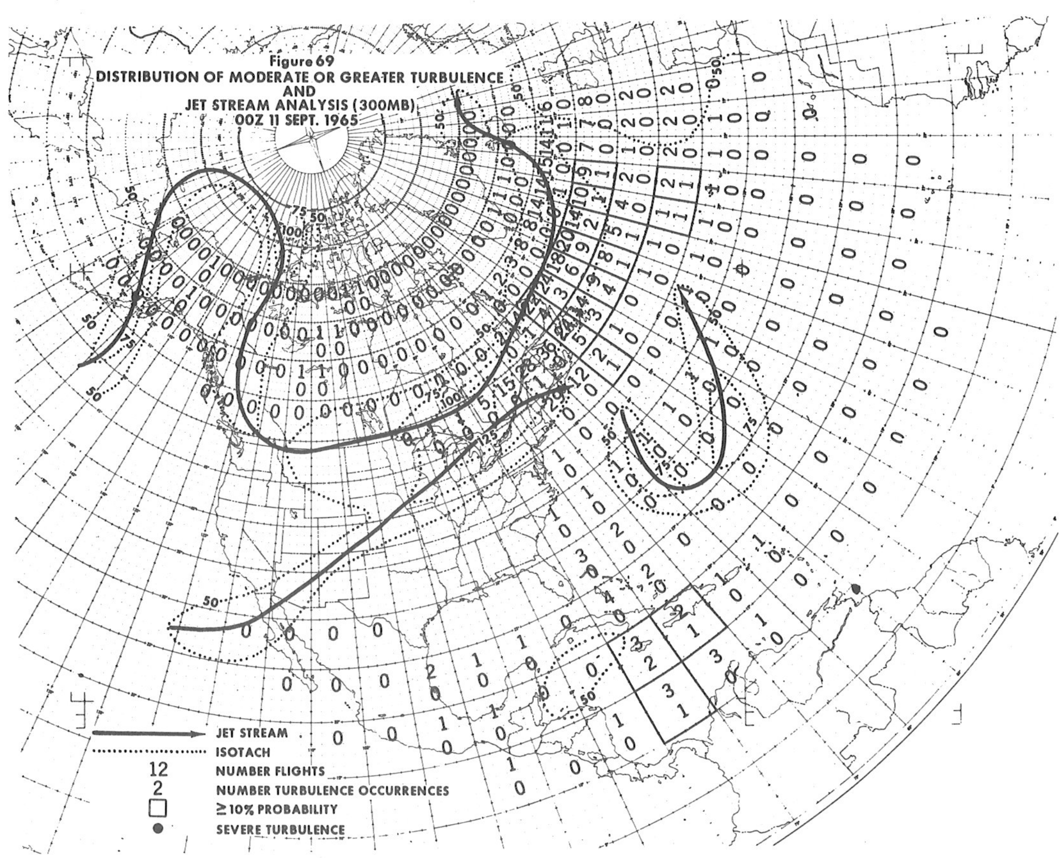
Figure 69
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 11 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥ 10% PROBABILITY
SEVERE TURBULENCE

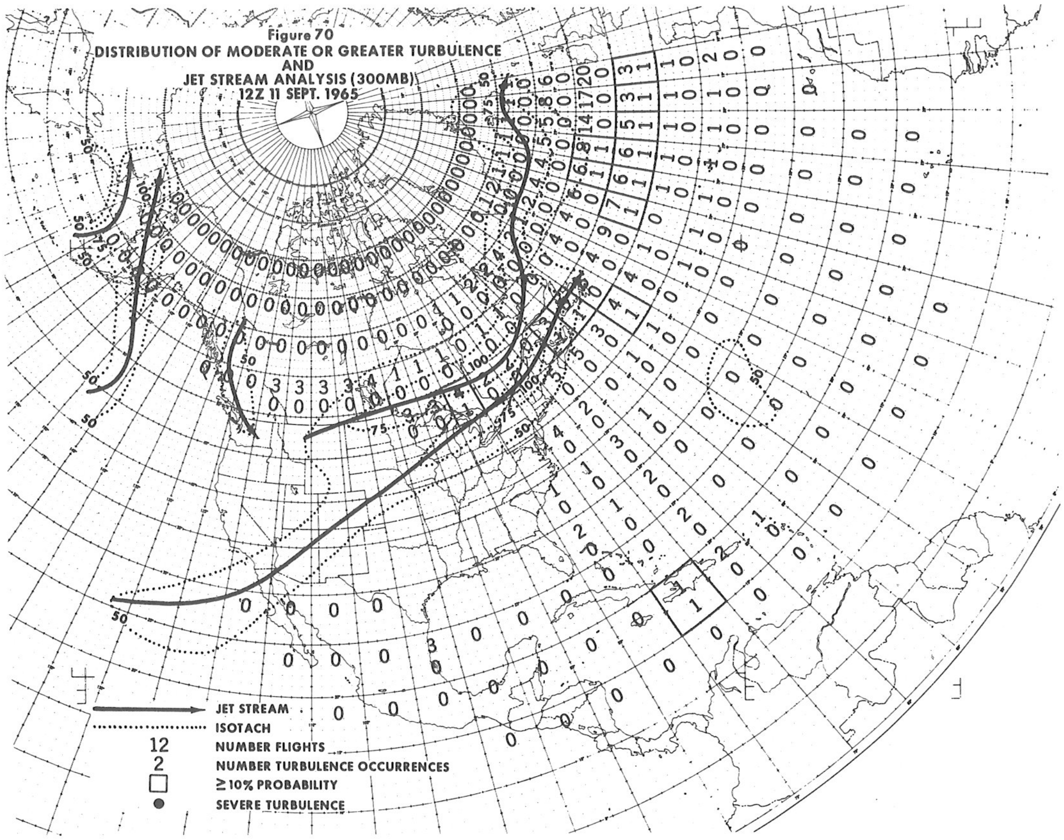
Figure 70
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
12Z 11 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

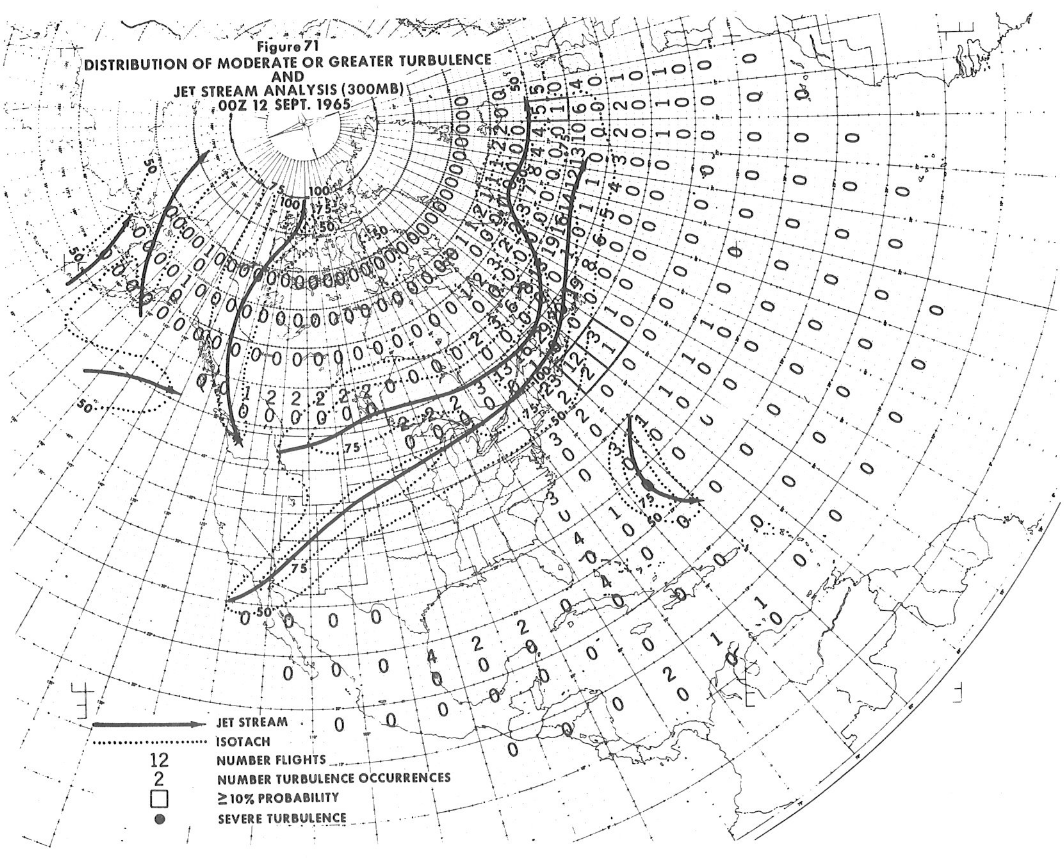
Figure 71
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE
AND
JET STREAM ANALYSIS (300MB)
00Z 12 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

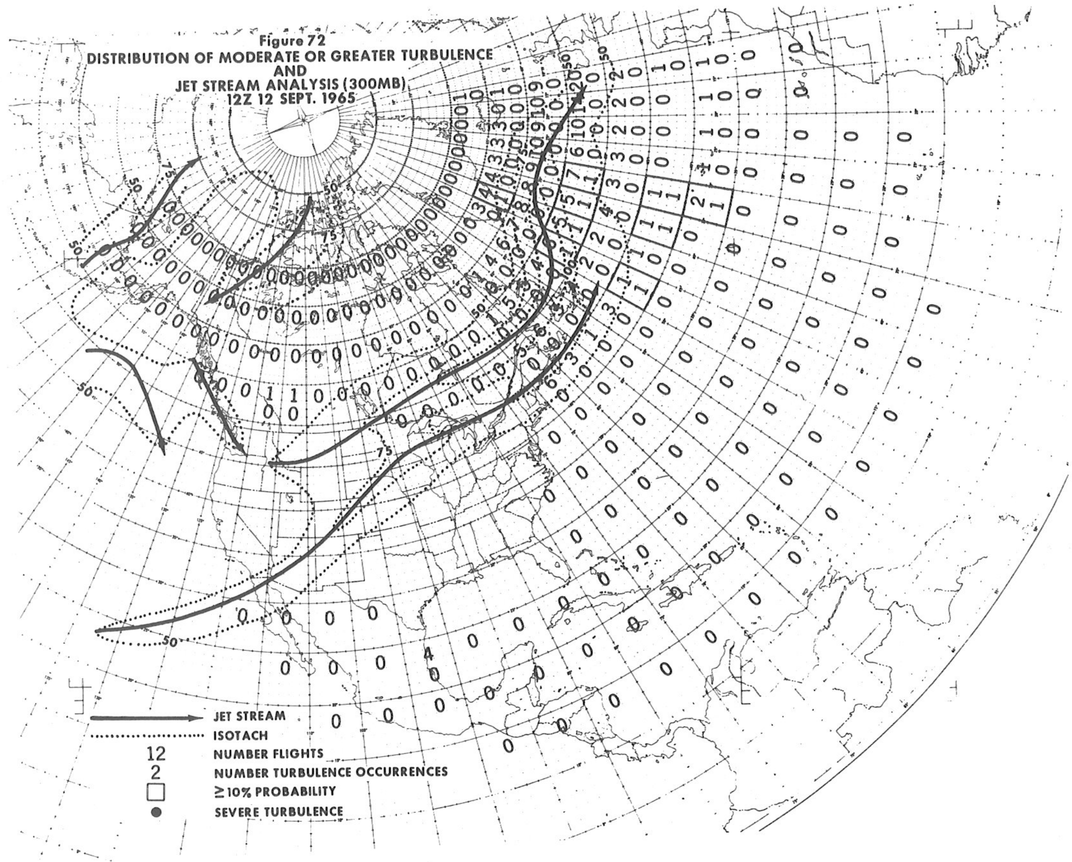
Figure 72
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE AND JET STREAM ANALYSIS (300MB) 12Z 12 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

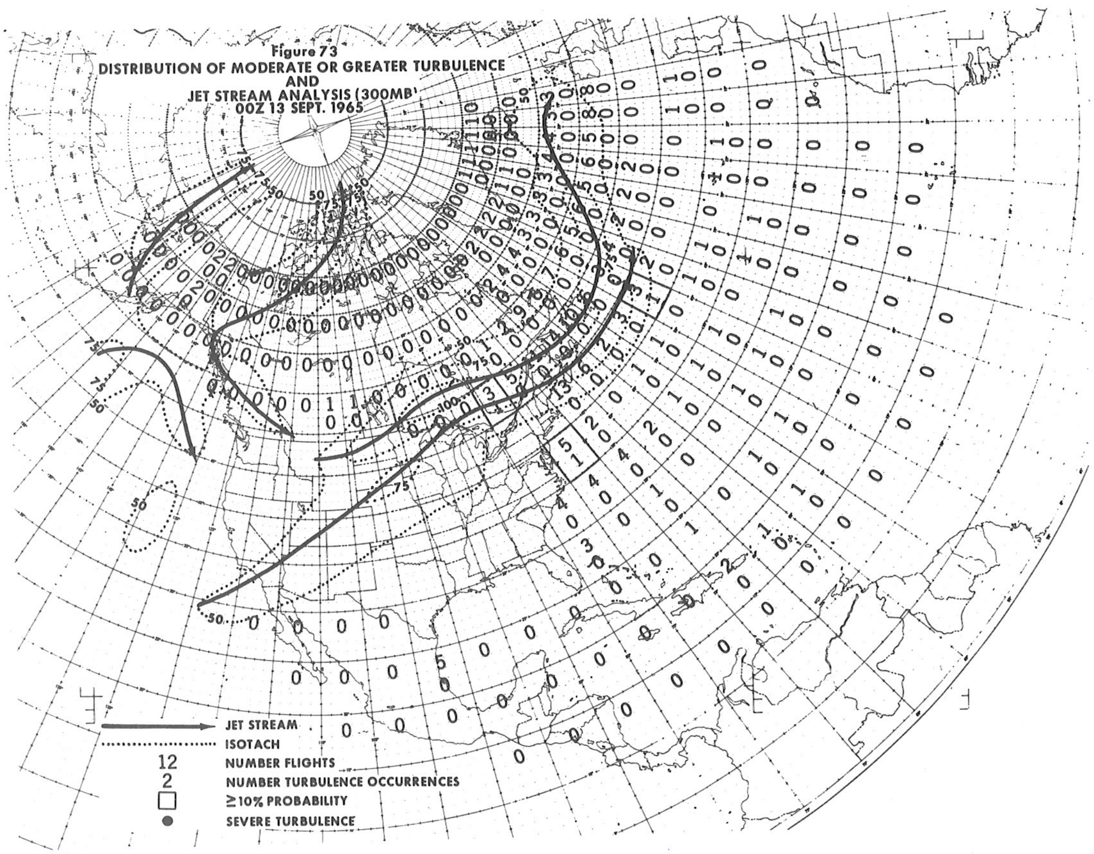
Figure 73
DISTRIBUTION OF MODERATE OR GREATER TURBULENCE AND JET STREAM ANALYSIS (300MB) 00Z 13 SEPT. 1965
JET STREAM
ISOTACH
12 NUMBER FLIGHTS
2 NUMBER TURBULENCE OCCURRENCES
≥10% PROBABILITY
SEVERE TURBULENCE

VI. GENERAL SUMMARY BASED ON DATA FROM ALL FOUR COLLECTION PERIODS

A. VARIATION OF TURBULENCE WITH ALTITUDE

The actual distribution of both the total number of flight squares and turbulence occurrences (based on tabulation by 5-degree squares) over North Atlantic, Alaska, Canada, Greenland, Caribbean, Mexico, and Central America is shown in Table IX by altitude layers for all four data collection periods. Percentages of flight squares with no turbulence, light or greater turbulence, moderate or greater turbulence, and severe turbulence are also included.

TABLE IX. DISTRIBUTION OF TURBULENCE WITH ALTITUDE

LAYER	TOTAL FLIGHT SQUARES	NUMBER OF OCCURRENCES OF INTENSITY NONE	LGT	MOD	SEV	PERCENT WITH NONE	≥ LGT	≥ MOD	SEV
A (<30,000 Ft.)	2229	1803	274	148	4	81	19	7	0.2
B (30,000 - 33,999 Ft.)	7504	6240	814	435	15	83	17	6	0.2
C (≥34,000 Ft.)	8837	7835	627	341	34	89	11	4	0.4

The percent of flight squares with no turbulence increased, the percent with both light or greater and moderate or greater turbulence decreased, and the percent with severe turbulence increased as the altitude increased. This general trend was consistent in each of the various regions and for each of the data periods, except that there was a smaller difference between the values in the two lower layers for Alaska, Canada, Greenland, the Caribbean, Mexico and Central America than for the North Atlantic. In the tabulation of the December data over the conterminous 48 states, the percent of flight squares with moderate or greater turbulence was 11, 8, and 6 respectively in layers A, B, and C. (1).

B. DISTRIBUTION OF TURBULENCE WITH SEASON

The frequency distribution of the various intensities of turbulence by squares for the entire area, Alaska, Canada, Greenland, the North Atlantic, Caribbean, Mexico, and Central America, for the four data periods is given in Table X.

TABLE X. DISTRIBUTION OF TURBULENCE BY SEASONS

ALASKA, CANADA, GREENLAND, NORTH ATLANTIC, CARIBBEAN, MEXICO, CEN. AMERICA

PERCENT	DECEMBER	MARCH	JUNE	SEPTEMBER
NONE	84	87	88	83
≥LGT	16	13	12	17
≥MOD	6	5	4	6
SEV	0.5	0.3	0.1	0.3
CONTERMINOUS 48 STATES (Based on 2-1/2 x 2-1/2 degree squares)				
NONE	75	82	82	83
≥LGT	25	18	18	17
≥MOD	8	6	5	3
SEV	0.4	0.3	0.2	0.1

The percent of flight squares with no turbulence increased, and the percent with all turbulence intensity classes decreased from the December through the March and June 5-day periods, but these trends reversed in the September period. Over the conterminous 48 states (lower half of Table X), the frequencies decreased even through the September period.

Since the data collection periods were only 5 days in duration, the above results may not represent true seasonal differences. The actual weather patterns within the 5-day periods may be more important. In the results over the conterminous 48 states (1), a significant variation was noted in both the weather pattern and the turbulence frequencies within the 5-day March period. Table XI indicates a large variation in the values of the turbulence frequencies for the 10-0000 through 12-120000Z period, as compared to the values in the 13-0000 through 15-0000Z period and in the entire 5-day period.

TABLE XI. VARIATIONS IN FREQUENCIES OF TURBULENCE WITHIN MARCH DATA PERIOD (CONTERMINOUS 48 STATES)

PERCENT	10-0000 12-1200Z	13-0000 15-0000Z	10-0000 15-0000Z
NONE	77	90	82
≥LGT	23	10	18
≥MDT	8	3	6
SEV	0.4	0.1	0.3

As can be seen from the above results, the variation within the data periods may be greater than the difference between data periods, depending on the weather patterns. The September weather situation was one with well developed upper level troughs and ridges over the Atlantic and southeastern Canada, with sharp curvature in the flow around these systems. The normally low incidence of mountain wave activity during September may partially explain the lower turbulence frequencies over the United States during this period as compared to the December and March periods.

C. VARIATION IN FREQUENCY OF TURBULENCE OVER LAND AND OCEAN AREAS

Considerable speculation has been given to the relative frequency of turbulence over land and ocean areas, but sufficient data has not been previously available to answer this question. It was hoped that the ICAO data would prove sufficient to help answer this question.

The tabulations of turbulence occurrences over the conterminous 48 states in the previous reports (1, 2) were made using 2-1/2-degree latitude-longitude squares, while it was necessary to use 5-degree squares for the rest of the ICAO data. From a sample tabulation using both 2-1/2 and 5 degree squares, a conversion factor was obtained so that the results would be comparable. The frequencies or probabilities of light or greater, based on tabulation by 5-degree squares were 1.6 times greater, the frequencies of moderate or greater were 1.8 times greater, and the frequencies of severe turbulence were 2 times greater than those based on tabulation by 2 1/2-degree squares.

Comparisons were made between the adjusted frequencies over the conterminous 48 states and those over that portion of the N. Atlantic at the same latitudes (25 - 45°) for all four data periods. Comparisons were also made of the turbulence frequencies over Alaska, Canada, and Greenland with those over that portion of the North Atlantic at the same latitudes (45 - 70°) for all four data periods. In this latter comparison of turbulence frequencies, all tabulations were based on 5-degree squares. Table XII shows these comparisons of turbulence frequencies over land and ocean areas.

TABLE XII. VARIATION IN FREQUENCY OF TURBULENCE OVER LAND AND OCEAN

PERCENT OF	U. S. (ADJUSTED)	N. ATLANTIC (25-45^{O}N)	ACG*	N. ATLANTIC (45-70^{O}N)
NONE	69	81	84	88
$\geqslant$LGT	31	19	16	12
$\geqslant$MOD	9.7	7.0	5.6	4.5
SEV	0.4	0.0	0.4	0.2

* (ALASKA, CANADA, GREENLAND)

	U. S. (ADJUSTED)	N. ATLANTIC (25-45^{O}N)	U. S. (ADJUSTED)	N. ATLANTIC (25-45^{O}N)
	DECEMBER		SEPTEMBER	
NONE	60	77	73	81
$\geqslant$LGT	40	23	27	19
$\geqslant$MOD	14.3	8.0	4.9	6.0
SEV	0.8	0.2	0.0	0.0

While the frequencies of all turbulence intensity classes over the United States were higher than the values over the corresponding latitudes of the North Atlantic (25 - 45^{O}N), the increase in the frequency of moderate or greater turbulence was much less than the increases in the other intensity classes. The actual frequency of moderate or greater turbulence over the United States was not greatly higher than the frequency over the corresponding latitudes of the North Atlantic. The frequency of light or greater turbulence over the ACG area was higher than the frequency over the corresponding latitudes of the North Atlantic (45 - 70^{O}N), but this increase was less pronounced than in the United States comparison. The frequency of moderate or greater turbulence over the ACG area was not much higher than the frequency over the corresponding latitudes of the North Atlantic.

The lower part of Table XII shows an interesting seasonal trend. The frequencies of all intensities of turbulence were much greater over the United States than over the corresponding latitudes of the North Atlantic during the December period. However, in the September period, the increase in the frequency of light or greater turbulence was not as great as in the December period. The frequency of moderate or greater turbulence in the September period was actually lower over the United States than the frequency over the corresponding latitudes of the North Atlantic. This contrast in the results for December and September was probably due to the difference in mountain wave activity in the two periods. No similar seasonal variation was evident in the comparison of values over the ACG and its corresponding latitudes of the North Atlantic. Most of the turbulence data over Canada was confined to southeastern Canada where mountain wave activity was not as prevalent.

One might conclude that if the effect of mountain wave activity is dominant, the frequencies will be higher over land than over water. If the turbulence is mostly due to upper level troughs, ridges, and jet streams, the difference will not be so great. In any case, the difference in frequency of high level turbulence over land as compared to that over water was not as great as had been thought in the past.

D. DURATION OF TURBULENCE AS A FUNCTION OF INTENSITY

A tabulation of the duration of turbulence occurrences was made from the data on the original flight cards. Values of the mean duration and the standard deviation of the mean are presented in Table XIII for different intensities of turbulence. In the following tabulation, the light to moderate cases were combined with the light occurrences. The light to moderate reports undoubtably contained many cases where the actual turbulence was light for most of the time period but occasionally moderate. For a similar reason, the moderate to severe cases were combined with the moderate reports.

TABLE XIII. DURATION AS A FUNCTION OF TURBULENCE INTENSITY

INTENSITY	LIGHT AND LIGHT TO MODERATE	MODERATE AND MODERATE TO SEVERE	SEVERE	
MEAN	15.7	11.1	6.6	minutes
STANDARD DEVIATION	17.2	12.2	3.8	

The trend towards shorter mean values of the duration of turbulence with increasing intensity of turbulence appears reasonable. However, the scatter in the individual values used to obtain the means was very great, as can be seen in the values of the standard deviations. It would appear that not too much significance can be attached to the actual values of the means.

E. VARIATION OF AIR SPEED AND INTENSITY OF TURBULENCE

Some speculation has been made about the possibility of using air speed fluctuation as a measure of turbulence intensity. The tabulation of the mean air speed fluctuations and standard deviation of these values can be found in Table XIV for the different intensities of turbulence.

TABLE XIV. AIR SPEED FLUCTUATIONS AS A FUNCTION OF TURBULENCE INTENSITY

INTENSITY	LIGHT	LIGHT TO MODERATE	MODERATE	MODERATE TO SEVERE AND SEVERE	
MEAN	2.9	5.3	8.4	16.6	(knots)
STANDARD DEVIATION	4.0	5.3	8.0	11.2	

While the mean value of the air speed fluctuations increased steadily as the reported turbulence became more intense, the actual values of the means can not be relied upon as actual criteria of turbulence intensities. The standard deviations are nearly as large and in some cases larger than the individual means and are much larger than the differences between the mean values for the different intensities.

VII. SUMMARY AND CONCLUSIONS

This study has produced some interesting meteorological and climatological information on clear air turbulence. The most striking meteorological situations were those on 11-12 December 1964, 12-13 March 1965, and 10-11 September 1965, when well developed 300-mb circulation patterns were associated with unusually large frequency of turbulence and more intense turbulence. However, aside from these relationships, the study has not produced a set of sharply defined criteria which can be used to estimate or predict CAT on a routine basis. Turbulence was reported over some regions without any apparently significant meteorological patterns. Other situations with well-developed meteorological patterns, which should have been conducive to turbulence, did not show turbulence. In some of the latter situations, the number of flights over those areas was insufficient for adequate testing.

Even though the data from this ICAO data collection program were better than those used in other studies, a definite need exists for better turbulence data. Some data cards had to be discarded because the date, time, route, or flight level were not reported. Other flights were difficult to reconstruct due to incomplete data on actual route or changes of flight level, and to the lack of a reported arrival time. Data on turbulence encounters were reasonably complete so far as the intensity, position, time, and flight level were concerned, but many of the other items were not always filled out. Both more comprehensive and accurate routine flight reports and data from research flights into suspected turbulence zones will be required.

The results from this study are in general agreement with those obtained from the more detailed analyses over the conterminous 48 states. These studies (1, 2) indicated the importance of upper level troughs with sharp curvature and of jet streams with sufficiently strong vertical wind shear. They also indicated that, with other factors being equal, greater consideration should be given to curved than to straight segments of jets. Areas in which wind speed, vertical and horizontal wind shear, and contour gradients were increasing with time were conducive to turbulence.

In addition to the above points, this study has shown the importance of sharply curved flow patterns. This is in agreement with an earlier study (3) which pointed out the importance of vorticity. The present study has particularly pointed out the importance of sharply curved anticyclonic flow patterns around high pressure ridges.

It is hoped that the data and discussions in this paper will contribute to an improved understanding of clear air turbulence and will suggest further investigations and studies.

VIII. REFERENCES

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2. "Forecasting Clear-Air Turbulence by Computer Techniques," R. M. Endlich and R. L. Mancuso. September 1967.

3. "Analysis of Special CAT Data Collection Program February 4 - 9, 1963, DeVer Colson. 1964.

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